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ECONOMIC ANALYSIS OF ALTERNATIVE SLUDGE DISPOSAL METHODS IN VERMONT

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VERMONT WATER RESOURCES RESEARCH CENTER

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16. Abstract

~~This study provided~~ information is provided on the costs of municipal sewage sludge disposal in Vermont. Specific objectives were to determine the costs of ~~the~~ two methods of disposal, landfill and landspreading, ~~which are being used in Vermont and~~ determining factors which influenced disposal costs; determining the economic benefits of landspreading disposal, and designing a regional plan for sludge disposal.

The data were obtained by use of three survey questionnaires. The first, ~~was~~ used in interviews with operators of twenty wastewater treatment plants, gathered information on sludge disposal practices and the costs associated with these practices. Two additional questionnaires were used to survey current and potential users of sludge to provide information concerning landspreading practices and costs.

There was no indication that either ~~of the two~~ methods of disposal, ~~landfill or landspreading~~, was less expensive than the other. An analysis of variance indicated, however, that per capita disposal costs associated with the use of flotation thickeners and vacuum filters were significantly higher than those associated with liquid

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An initial evaluation of regional efforts to manage and dispose of sludge ~~were~~ was carried out. Evidence indicates that increased regional efforts may reduce disposal costs and facilitate increased landspreading. One specific regional approach was put forward.

ECONOMIC ANALYSIS OF ALTERNATIVE SLUDGE DISPOSAL METHODS IN VERMONT

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ABSTRACT

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This study was designed to obtain information on the costs of municipal sewage sludge disposal in Vermont. A major objective of the study was to determine the costs of the two methods of disposal, landfill and landspreading, which are being used in Vermont. Additional objectives included determining factors which influenced disposal costs, determining the economic benefits of landspreading disposal, and designing a regional plan for sludge disposal.

The data for the study was obtained by use of three survey questionnaires. The first questionnaire used in interviews with operators of twenty wastewater treatment plants, gathered information on sludge disposal practices and the costs associated with these practices. Two additional questionnaires were used to survey current and potential users of sludge. These provided information concerning landspreading practices and costs.

Several conclusions were drawn from this data. There was no indication that either of the two methods of disposal, landfill or landspreading, was less expensive than the other. An analysis of variance indicated, however, that per capita disposal costs associated with the use of flotation thickeners and vacuum filters were significantly higher than those associated with liquid and sand drying bed dewatered sludge disposal. Total costs of liquid sludge disposal were much more responsive to changes in distances to disposal sites than were total costs associated with dewatered sludge disposal. Other factors, especially weather, were often more important than economic considerations in choosing a disposal method.

The nutrient value of sludge when used as a fertilizer supplement was $34.60 per ton in 1976 and many Vermont farmers are now spending time and money to obtain sludge. The sale of sludge has potential for communities to receive portions of sludge disposal costs.

An initial evaluation of regional efforts to manage and dispose of sludge were carried out. Evidence indicates that increased regional efforts may reduce disposal costs and facilitate increased landspreading. One specific regional approach was put forward.

Key Words: Sludge*, sludge disposal*, land disposal of sludge, wastewater sludge, organic fertilizers, sludge burial*, costs of disposal*, small communities, regional cooperation, sludge treatment and processing, economic analysis.

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INTRODUCTION

> The primary objective of a wastewater treatment plant is to prevent pollution of streams, lakes, and groundwater supplies, by removing the solid pollutants from the wastewater. The solids are removed in the form of a liquid slurry, called sludge. Sludges are concentrated pollutants.[1]

Why Study Sludge Disposal in Vermont?

The disposal of sludge has been one of the largest problems faced by wastewater treatment plants throughout the United States. It is no less so for the 64 wastewater treatment plants in Vermont as the Vermont Agency of Environmental Conservation has pointed out. "Over the past several years, the treatment, handling, and ultimate disposal of sludge has probably been the most difficult problem in the operation of municipal treatment facilities. It is imperative that the alternate methods of handling and disposal/utilization be fully itemized and evaluated from a dependability, environmental, and cost-effective standpoint during facilities planning for new plants and upgrades..."[2] Not only is the existing problem severe, but as plants throughout the United States and Vermont are upgraded in the next few years, sludge volumes are expected to double

[1] Environmental Protection Agency, Characterization and Utilization of Municipal and Utility Sludges and Ashes (Ep 1.23/2:670/2-75-033a), Volume 1, Summary.

[2] Vermont Agency of Environmental Conservation - Environmental Engineering Division, Guidelines for Municipal Sludge Disposal Decisions: Draft (Unpublished guidelines, January 1976), page 1.

or triple, making the problem even greater. Although there has been a considerable amount of research on sludge handling and disposal in the recent past, most of it has been concerned with municipalities having much larger populations than those served by treatment plants in Vermont. Municipalities in Vermont serve smaller populations and handle and dispose of relatively small quantities of sludge. These small, rural, less densely populated towns experience problems which are quite different from those of larger, urban municipalities needing to handle and dispose of large amounts of sludge. These problems need to be examined.

There is considerable diversity among the 64 wastewater treatment plants in Vermont. Plants range in their capacities for wastewater treatment from 0.054 MGD (million gallons per day) to 4.0 MGD. Treatment plants serve as few as 280 people to as many as 25,000 people. In-plant sludge processing facilities and procedures differ substantially. Sludges are concentrated by gravity thickening or dissolved-air flotation. Sludges are sometimes digested in aerobic or anaerobic digesters and in sludge lagoons. Sludges are dewatered using sand drying beds, vacuum filters, or dual-cell dewatering units. Some sludges are conditioned using chemicals or by freezing. Combinations of these different processes result in different types of sludges. Both primary, untreated sludges and secondary sludges which have undergone different biological processes to remove organic matter may be found at Vermont treatment plants. At the end of treatment, sludges may contain as much as 99 per cent water or be almost completely dry. Even "dewatered" sludges may be from 50 per cent to 80 per cent water. The pH ranges of sludges vary

according to the treatment they have undergone. Some sludges contain chemicals in the form of heavy metals which have entered the wastewater treatment plant in the water being treated. Some sludges contain other types of chemicals, resulting from different methods of treatment. Amounts of sludges produced in Vermont towns that must be disposed of may range from 39 pounds per day in the smallest plants to 3500 pounds per day in the largest plants.

As pointed out in the introductory quotation, sludge is a by-product of another process, wastewater treatment. As such, wastewater treatment sludges in the United States have historically taken on a negative connotation. They are the concentrated form of an undesirable product, and their disposal has most often been viewed as a problem of getting rid of something which has a negative value. The positive value of human waste as a fertilizer and soil conditioner has been recognized in China for centuries.[3] In Europe, especially England, sludges from treatment plants have been used successfully for several decades.[4] In the United States, with the rapid increase and availability of inorganic fertilizers after World War II, the use of, interest in, and research on organic fertilizers declined rapidly. In recent years, as the quantity of sludge produced in the United States has increased, disposal has become a problem and landspreading as a disposal method has been increasingly used.

[3] F. H. King, Farmers of Forty Centuries of Permanent Agriculture in China, Korea, and Japan (Emmaeus, Pennsylvania: Organic Gardening Press, n.d.), p. 174.

[4] Alexander Elsner, Sewage Sludge: Treatment and Utilization of Sludge (London: McGraw Hill Book Company, 1912), p. 5.

More recently the greatly increased costs of fossil fuels, a major component in the manufacture of inorganic fertilizers, have stirred interest in sludge as a fertilizer with a positive value attached to it. As the price of inorganic fertilizers has risen, the value of sludge as a fertilizer in economic terms has also risen. The doubling of inorganic fertilizer prices will essentially double the value of sludge as a fertilizer because as a by-product of another process, its production costs are essentially zero. Future increases in inorganic fertilizer prices seem assured due to the growing scarcity of fossil fuels and an increasing demand for fertilizer materials. There is a need to determine and be able to forecast when the cost of landspreading sludge, if it is greater than other methods of disposal, is equal to its value in economic terms as a fertilizer. As the cost of petroleum products rises, the cost of transportation and therefore disposal costs will also rise, and this relationship needs also to be examined.

As people have begun to realize that fossil fuels are finite in quantity, the long term effects of our dependence on them has created concern and more interest in looking for alternatives. This includes alternatives for fossil fuel based inorganic fertilizers. There is a desire to shift away from dependence on finite resources to renewable resources. Sludge is a renewable resource, and its use bears investigation for this reason.

Along with the economic costs and benefits of different methods of disposal of sludge, there are other costs and benefits which need to be examined. These are the environmental costs and benefits. The problem

of trying to measure environmental quality or damage done by pollution is not an easy one. Things which must be considered cover a wide range. In the case of sludge disposal, human health may be involved. The value of clean streams and lakes for fishing and recreation is important. Some people receive pleasure simply from viewing a healthy stand of hay or corn regardless of its agricultural value. There is need to consider the environmental quality of Vermont and how it is affected by alternative means of sludge disposal. The treatment plant operators' views of the environmental effects of sludge disposal are important.

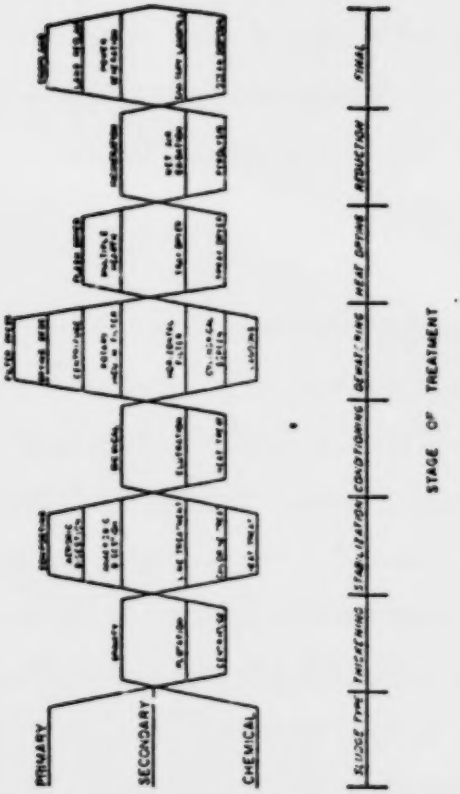
The Problem Defined

The process of wastewater treatment is not a simple one. There are many different options that a municipality may choose when constructing or upgrading a treatment plant. A schematic diagram of the major options available for the different processes involved in sludge processing and disposal is presented in Figure 1. The choice of one option over another in the different stages outlined will have different economic costs associated with it. It is not within the scope of this paper to discuss all of them. This study is only concerned with the final process of disposal. It must be recognized that the choice of any number of options previous to final disposal will affect the ultimate decision as to the proper disposal method. Different treatment processes will produce different sludges and thus affect the disposal method chosen.

"Disposal techniques for treated sludge which are feasible in Vermont's climate, topography, and economy generally fall into one of two

FIGURE 1

Sludge Processing and Disposal Alternatives: General[5]



[5] E. Alan Cassell, W. J. Siok, J. R. Senning, and R. G. Fritz, Sludge Treatment and Disposal by Small Communities: The State of the Art (Paper presented at the Northeastern Branch Meeting of the American Society of Agronomy, University of Vermont, Burlington, Vermont, June 26-29, 1977), p. 13.

categories: disposal by landfill-type operation or utilization as a fertilizer supplement to grow agricultural crops or reclaim land."[6] This generalized statement of conditions for disposal in Vermont seems to be accurate, and most treatment plants within the state are using one of these two methods. Roughly one-third to one-half of the treatment plants use landspreading as a method of sludge disposal. The rest use the landfill method of disposal. Ocean disposal is certainly not feasible because of distances involved. The use of sludge for power generation has been under investigation for some time and technology in this area is increasing. Some treatment plants in Vermont do use methane produced in the plant for heating anaerobic digestors and treatment plant buildings. Further investigation in this area is still needed.

Disposal of sludge in landfills occurs after sludges have been either fully or partially dewatered, usually by sand drying beds or vacuum filtration. The trucks used for sludge removal range in size from pickup trucks to 5 cubic yard dump trucks. Sludges are transported distances ranging from less than 0.25 miles to 15 or 20 miles to landfill sites. The sludge is then buried at the landfill site, usually by the landfill operator. The landfill must be state approved for sludge disposal purposes by the Environmental Conservation Agency of Vermont. Unlike landfill disposal, landspreading of sludge can be accomplished without the dewatering of the sludge. Tank vehicles carry liquid sludge to landspreading sites and spread it directly on the land. Tank vehicles vary

[6] Vermont Agency of Environmental Conservation, Guidelines for Municipal Sludge Disposal Decisions: Draft, page 2.

from home-made units with tanks mounted on flatbed trucks or wagons to tanker trucks with high flotation tires built specifically for the transportation and spreading of sludge. Dewatered sludges are also spread on landspreading sites using vehicles similar to those used for landfill disposal. Distances to landspreading sites also vary considerably. In some cases dewatered sludges are stored or stockpiled at either the treatment plant or landspreading site before being spread.

The choice between landfill or landspreading as disposal methods involves investment and operating decisions on the part of the treatment plant managers or operators. There are several options available for carrying out either method. Different options will have different costs and benefits associated with them. Storage capacities of plants, proximity to landfills or lands appropriate for spreading, equipment needed, operations and maintenance expenses, health and environmental regulations, town revenues, and negative attitudes toward human waste and its use are a few of the factors which may affect the final decision. Individual municipalities may find some of the costs associated with certain landfill or landspreading methods prohibitive. If rural municipalities were able to combine their resources and capital, particularly in the final disposal stage, economies of scale might be achieved. The problem of developing a regional approach to sludge disposal in Vermont will be one area of investigation, and the development of a feasible regionalized approach will be one objective.

Many of the problems experienced by wastewater treatment plant operators in Vermont are due to climatic conditions. In many cases

throughout the state, drying beds do not work effectively. Because both drying beds and sludge freeze in the winter, more than one application of sludge to drying beds during winter months is often not possible. This creates difficulties for some treatment plants which do not have the capacities to store sludge through the winter. Drying beds often do not work well in the non-winter months due to rain and poor subsurface draining. Odor created by sludges on drying beds, especially in the summer, is sometimes offensive. Spreading sludge on cropland in the winter can be a problem due to runoff and inaccessibility to fields. In the spring when sludge spreading is often most desirable, it is sometimes too wet to get on the fields.

When considering landfill or landspreading disposal, transportation equipment and costs must be considered. Many towns have trucks suitable for transportation of some dewatered sludges, but to transport liquid sludges some form of mobile tank unit is needed which towns seldom have on hand. The cost of commercial liquid sludge transporting and spreading equipment is high and usually beyond the reach of small municipal budgets. When landfills are used for disposal, they are often quite far from treatment plants. The cost of transportation is higher in these cases. In addition, the landfill charges are often considerable.

The imposition of wastewater treatment regulations on small Vermont communities creates another type of problem. Towns are often faced with manning and operating a facility (the treatment plant) and carrying out processes (wastewater treatment, sludge processing, and sludge disposal) with which they have had no prior experience. The amount of information

available and options open for processing and disposing of small quantities of sludge is limited. Guidelines and suggestions provided by engineers and government agencies are often not detailed enough or fully suited for specific towns. Towns often do not have the means of obtaining the necessary information to be able to economically run a treatment plant in an environmentally sound manner. Many treatment plant operators have other jobs, either with the town or elsewhere, and can not concentrate fully on treatment plant problems. Although many options may exist for treatment and disposal, possibilities are not fully explored and suboptimal decisions are often made.

This study concentrated on options available to Vermont treatment plants for the disposal of sludge by either the landfill or landspreading methods. The objectives of the study were to:

1. Determine the economic costs and benefits of both the landfill and landspreading methods of sludge disposal in Vermont;
2. Determine the relationship of rising fuel and inorganic fertilizer prices to the economic costs and benefits associated with the two methods of disposal;
3. Determine the extent of environmental consideration given by wastewater treatment plant operators in the process of sludge disposal;
4. Develop a method and financial scheme for a regionalized approach to sludge disposal in Vermont.

Hypotheses

At the present time, the value of sludge as a fertilizer and soil conditioner has not been fully recognized in Vermont. There is environmental concern over pollution caused by sludge disposals in landfills. Landspreading disposal of sludge is being viewed more and more as the preferable means of sewage sludge disposal. With these considerations in mind, the following set of hypotheses were formulated.

1. The economic and environmental benefits of landspreading sludge are greater than the economic and environmental benefits of landfill disposal.
2. The economic costs of landfill disposal are less than the economic costs involved in landspreading.
3. Environmental costs are greater in disposal of sludge by landfill than in disposal by landspreading.
4. If farmers or other users paid a "fair" price for the benefits they received from sludge, independent treatment plants and towns would find landspreading disposal as economically feasible as landfill disposal.
5. Small treatment plants will gain economic benefits in some site specific cases if they group together to dispose of sludge, gaining economies of size in the final disposal process.

METHODOLOGY

This study was part of a larger project at the University of Vermont involving several different university and medical school departments. The Plant and Soil Science Department, Water Resources Department, Department of Microbiology and Biochemistry, and Economics Department from the University and the Department of Medicine from the College of Medicine were all involved. Under investigation were treatment plant designs, crop responses to sludge application, mechanical devices for applying liquid sludge, and the health risks involved with sewage sludge use, as well as the economic and environmental aspects of sludge disposal with which this study was concerned.

Because this particular pilot study was the first of its kind done in Vermont, many areas within the economic realm of sludge disposal were explored. This necessitated the use of a broad range of methods and techniques to develop a more complete picture of all that is involved with the economics of sewage sludge disposal. For this reason, this study is divided into several parts, some of which were incorporated as more information was gathered and the need became apparent for further investigation or clarification. Each of these areas of investigation necessitated the use of different methodological techniques to obtain the information that was needed. The different methodologies used are discussed below.

Cost Investigation

As indicated earlier, there is considerable variety among the 64 wastewater treatment plants throughout Vermont, both in their in-plant facilities and in their sludge disposal practices. Resources for this research did not allow an in-depth examination of all treatment plants or all disposal methods. It was felt that an in-depth examination of a sample of representative treatment plants could be used for purposes of this study. This sampling approach facilitated the selection of treatment plants in different geographic locations within the state. It also enabled the selection of treatment plants in close proximity to each other which it was felt might be able to combine resources used for sludge disposal. Twenty treatment plants were selected from three different areas of the state. These areas and the treatment plants within them were felt to be representative of different situations currently found in Vermont.

1. Sampling

The area representing Vermont's largest treatment plants and those serving the largest populations was the Burlington area. Treatment plants in this area, eleven in total, included three in Burlington, two in South Burlington, two in Shelburne, and one each in Winooski, Colchester, Essex Junction Village, and the town of Essex. Treatment plants in the Burlington area ranged in size from .250 MGD design capacity to 4.0 MGD design capacity. They served from 1700 to 25,000 people. Sand drying beds, flotation thickeners, and vacuum filters were used to dewater sludge.

The second area chosen, hereafter referred to as the Southern area, included the following six wastewater treatment plants: West Rutland, Wallingford F. D. 1, Poultney, Fair Haven, Castleton, and Pittsford. This group was felt to be representative of a middle range of treatment plants found in Vermont. Neither the smallest nor the largest treatment plants found in Vermont were in this group. They were rural, as technically is all of Vermont, but not as isolated as some other treatment plants in other Vermont communities. The Environmental Conservation Agency of Vermont had previously chosen this group of plants to investigate the feasibility of joint investment in a liquid sludge disposal vehicle, so it was felt that this would be a good area to investigate further. Treatment plants in the Southern area ranged in size from .070 MGD design capacity to .380 MGD design capacity. They served from 750 people to 3300 people. Sludge dewatering in this area was done exclusively on sand drying beds.

The third area, hereafter referred to as the Northern area, consisted of three treatment plants in relatively small, remote communities. These plants were new or under construction at the time data was being collected. One treatment plant was in operation and the other two were to open some time in 1977. These plants provided an opportunity to investigate some of the problems faced by new treatment plants. The plants were located in North Troy, Enosburg Falls, and Sheldon Village. The Northern area treatment plants were designed to process from .054 MGD to .280 MGD of wastewater and built to serve from 280 people to 1200 people. Sludges are to be dewatered using sand drying beds and, in one case, a dual-cell dewaterer.

A map showing the location of the three areas chosen is found in Figure 2. Table 1 lists all twenty treatment plants, populations served, design capacities, and sludge dewatering equipment available for use prior to disposal.

2. Data Collection

In conjunction with the Water Resources Department at the University of Vermont, a questionnaire was designed to gather information concerning several aspects of wastewater treatment and sludge disposal (Appendix I). Each of the operators of the treatment plants selected was interviewed during the spring of 1977. After initial analysis of the questionnaires, some treatment plant operators were recontacted to clear up information or gain information not obtained during the initial interview.

Sections of the questionnaire of primary concern in this study were those entitled "General Plant Data," "Present Disposal Practices and Costs," "Environmental Considerations," and section H which asks the question, "Are there any ways the operator feels the town could save more money in either processing or removal, including more private removal?". Information gathered from treatment plant operators covering the "Present Disposal Practices and Costs" section of the questionnaire provided most of the information needed to calculate costs of the methods of disposal used in Vermont with which this study was concerned. The "Environmental Considerations" section gave an indication of how much consideration was given to the environment by treatment plant operators in the practice of sludge disposal. The question in section H helped provide an understanding

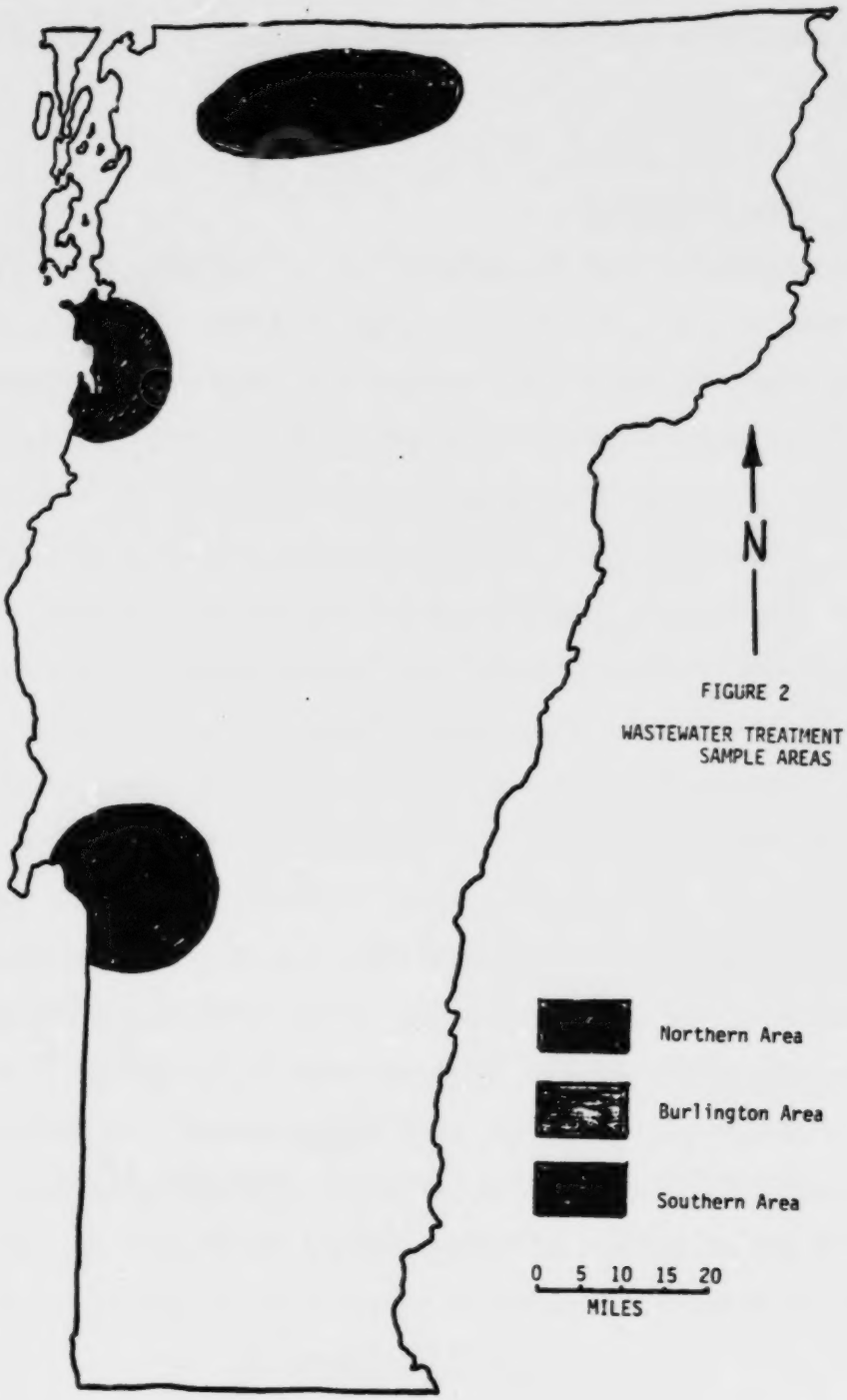


FIGURE 2

WASTEWATER TREATMENT PLANT
SAMPLE AREAS

TABLE 1

WASTEWATER TREATMENT PLANTS

INCLUDED IN SURVEY

Treatment Plant	Population Served	Design Capacity (MGD)	Available Dewatering Equipment
Burlington Area			
Burlington (Main)	25,000	4.0	flotation thickeners and vacuum filters
Burlington (North)	9,000	2.0	
Burlington (East)	5,000	1.0	
S. Burlington (Bartletts Bay)	3,000	.700	
S. Burlington (Airport Parkway)	6,400	1.200	
Shelburne F.D. 1	1,200	.250	
Shelburne F.D. 2	3,000	.450	
Winooski	7,400	1.200	
Colchester	2,500	.310	
Essex Junction Village	6,000	1.200	
Essex	1,500	.600	
Southern Area			sand drying beds
West Rutland	2,900	.250	
Wallingford F.D. 1	750	.090	
Poultney	3,000	.300	
Castleton	3,000	.380	
Fair Haven	2,700	.250	
Pittsford	1,750	.070	
Northern Area			
North Troy	700	.110	
Sheldon Village	280	.054	
Enosburg Falls	1,200	.280	dual-cell dewaterer

of the operators' perceptions of the economic problems they faced and gave them an opportunity to voice their opinions in this matter.

3. Description of the Data

Each of the treatment plants was found to have some form of landfill or landspreading type of disposal. Before disposing of sludge in landfills, sludge was dewatered using either sand drying beds or flotation thickeners in combination with vacuum filters. Both dewatered and liquid sludges were disposed of by the landspreading method.

In treatment plants using sand drying beds, sludge was typically emptied to the drying beds in the late fall and/or early spring. Sometimes, though much less frequently, sludge was added during summer months. The individual treatment plant schedules varied considerably. After sludge had dewatered adequately on the drying beds, the beds were cleaned by removing the sludge. Often times, considerable amounts of sand were removed with the sludge. Bed cleaning operations were performed depending on the treatment plant from one to ten times a year. Drying beds were cleaned either by hand tools and hand labor alone or in combination with a bucket loader. The transport vehicles used to bring the sludge to the ultimate disposal sites were pickup trucks, pickup trucks with trailers, or dump trucks. Vehicles and labor involved in sludge transport were supplied by the treatment plant itself, the town in which the treatment plant was located, or by private individuals. Sludges dewatered on sand drying beds were disposed of in both landfills and by landspreading.

Sludges being dewatered using vacuum filters were loaded directly

into dump trucks by means of a conveyer belt attached to the vacuum filter. From the treatment plant they went to a landfill. The operations of the flotation thickener in combination with the vacuum filter and the sludge disposal operations for these plants were carried on year round due to the large amounts of wastewater being treated in these plants. In these cases the treatment plant supplied both the labor and the dump trucks needed for sludge removal.

Sludges being disposed of in liquid form were transported in one of two ways. Tanks were often temporarily mounted on trucks during disposal operations to transport liquid sludge to disposal sites. In one case, a permanent tank truck vehicle had been made from a flatbed truck and a 2000 gallon water tank. Liquid sludge would usually be disposed of on cropland in early spring or late fall. Some liquid sludge was spread on pasture during summer months. Both treatment plants and private individuals supplied transport vehicles and labor for liquid sludge disposal.

4. Cost Determination

Little specific information was available in the literature on the costs of sludge disposal for treatment plants with design capacities of less than 0.5 MGD. A computerized literature search was utilized to supplement original findings and help ensure that no additional information was available. This search was performed at Northeastern University where all authors and titles of literature reference available at the library are put into computer memory along with short abstracts of the literature references. The computer is programmed to select references

from its file using key words in the combinations stated by the input data. Three lists of key words were submitted as part of the input data. All references having at least three of the key words, any one word from each list, were selected and printed along with abstracts. A list of 38 references resulted from this computer search, few of which supplied much additional helpful information. The lists of key words used and the prescribed formula are found in Appendix II. While little specific information was available for sludge disposal costs for wastewater treatment plants similar to the smaller sized plants found in Vermont, a good deal of literature did exist on disposal costs for wastewater treatment plants in general. The more helpful of these are listed in the bibliography, and those cited directly are footnoted.

Determination of both benefits and costs of alternate sludge disposal methods in Vermont was a major objective of this study. While both benefits and costs were involved, a traditional cost-benefit analysis was not performed. Cost-benefit analysis, in its usual application, is used to compare benefits and costs of alternative policies.[1] It is used for viewing broader alternatives for public investment over a long period of time.[2] In this case, the policy of building and using wastewater treatment plants to prevent pollution had already been chosen leading to the

[1] Henry M. Peskin and Eugene P. Seskin, eds., Cost-Benefit Analysis and Water Pollution Policy (Washington, D.C.: The Urban Institute, n.d.), page 1.

[2] A. R. Prest and R. Turvey, "Cost Benefit Analysis: A Survey," The Economic Journal, (December 1965), p. 683.

more immediate problem of sludge disposal. The more appropriate analysis for this study was an investigation of the cost-effectiveness of sludge disposal systems.

> Cost-effectiveness analysis estimates the costs of alternative methods to achieve a given policy. Since the policy objective is given, it is not necessary to compare it with other policy objectives. Thus, a crucial aspect of cost-benefit analysis, the need to measure the benefits in commensurate dollar units, is avoided.[3]

The cost-effectiveness analysis was performed from the viewpoint of society as a whole, not from the viewpoint of the individual treatment plants. That is, the alternative methods of disposal were evaluated in terms of the total resources used, not just in terms of the resources used or paid for by the individual treatment plants.

Disposal costs were calculated for all plants in operation for more than 18 months at the time of the interview. All costs were determined for 1976. Costs included only those of sludge processing and disposal, not total wastewater treatment costs. In several cases, different methods had been used in recent years by individual treatment plants to process and dispose of sludge. In these cases the costs of the method most commonly used was determined. In two cases the methods of disposal used in 1976 differed from those used in earlier years. These treatment plants had accurate records for both the current method and the method used prior to 1976. In these two cases, costs of processing and disposal for both methods at each of these two treatment plants were determined for 1976. A total of 17 treatment plants had been in operation for over 18 months at the time of the interviews, two of which supplied two sets of costs, giving a total of

[3] Peskin and Seskin, Cost-Benefit Analysis and Water Pollution Policy (n.d.), p. 2.

nineteen cost observations.

In order to determine costs and to facilitate comparison among the various treatment plants, certain assumptions had to be made concerning all treatment plant disposal costs. Assumptions were made concerning labor costs, capitalization rates, depreciation rates, rental rates of equipment, costs of supplies, and other operating costs. These assumptions and how they were used to determine total costs of sludge disposal are discussed below and outlined in Table 2.

Labor. All labor costs were calculated at the rate of $5.75/hour including overhead costs. This estimate was based on the average cost of labor for wastewater treatment plant personnel reported for two EPA studies.[4] The average cost of labor in each study was adjusted to 1976 by using an inflation rate of 6.25% per annum. The two adjusted costs of labor were then $5.55/hour from the study using 1971 costs and $6.00/hour from the study using 1973 costs. The use of $5.75/hour gave a cost of labor near the middle of this range. This cost of labor was used in calculating total costs of disposal in all but four cases. In three cases of estimating costs for operation and maintenance of flotation thickeners and vacuum filters, the labor costs were estimated by the plant superintendent. In one other case dealing with the operations and maintenance of sand drying beds, total operations and maintenance costs were given by the operator which included a cost of labor.

[4] Environmental Protection Agency, Cost Effective Wastewater Treatment Systems (EPA -430/9-75-002, July, 1975), n.p.; and Estimating Cost and Manpower Requirements for Conventional Wastewater Treatment Facilities (USEPA 17090 DAN 10/71), n.p.

TABLE 2

ASSUMED COSTS FOR SELECTED ITEMS*

Labor	$ 5.75/hour
Inflation Rate	6.25%/year
Amortization rate (20 year life & capital costs of 6.25%/year)	.08897
Bucket Loaders (including operator)	12.00/hour
Dump Trucks (including driver)	20.00/hour
Pickup Trucks	13.50/day plus .20/mile
Pickup Trucks with Trailers	15.00/day plus .20/mile
Insurance on Liquid Transport Vehicles	811.00/year
Registration of Liquid Transport Vehicles	6.00/year
Lime (delivered)	1.50/100 lbs.
Sand (delivered)	25.00/cu.yd.
Landfill Charges	5.00/trip

* See text for discussion of each item.

Capital Costs. When dewatering equipment was used prior to sludge disposal, the yearly capital cost of this equipment was added as part of the cost of sludge disposal. This was done for sand drying beds and vacuum filters. Due to the lack of information available for capital costs of flotation thickeners, yearly capital costs for this equipment were not included, resulting in a downward bias of the cost estimates in these cases. When dewatering methods were not used, these costs were not added to disposal costs even if such equipment was available at the treatment plant. Depreciation was not assumed to occur on dewatering equipment during years when it was not used, and therefore replacement investment was not necessary in these years.

Yearly capital costs for sand drying beds and vacuum filters were calculated by taking the estimated cost of construction or purchase and installation in the year of treatment plant construction and amortizing it over twenty years which was the expected life of these facilities. The estimated cost at the date of construction was based on unpublished work done by the Water Resources Department at the University of Vermont investigating in-plant costs of sludge processing at these same treatment plants. The amortization factor was .03897, based on a twenty year life with a cost of capital of 6.25% per annum.

Dewatered Sludge Transportation Costs. Transportation costs were based on equipment rental costs of the amount of time needed for disposal. The distances covered during disposal operations were considered as well when pickup trucks were used. When bucket loaders or dump trucks were used to clean drying beds or transport sludge, costs were $20/hour

including operator for a bucket loader and $12/hour for a dump truck including driver. When pickup trucks were used, a cost of $13.50/day plus .20/mile was used. Pickup trucks with trailers were costed at $15/day plus .20/mile. The labor used to drive the pickup trucks was considered to be separate. Rental rates were based on figures obtained from local equipment rental companies.

Liquid Sludge Transportation Costs. All costs for liquid sludge transportation vehicles were based on actual figures given by owners and operators of these vehicles. Annual capital costs were determined using initial capital cost of the vehicles depreciated straight line over seven years. Insurance costs ($811/year) and registration costs ($6/year) were included on town owned vehicles. Operations and maintenance costs were added based on treatment plant operator and individual owner information. All costs of labor for sludge transportation in liquid form were separate.

Supplies. Supplies used for operation and maintenance of sand drying beds included washed sand and lime. The costs for these supplies were obtained from current market prices at the rate of $25/cubic yard for sand and $1.50/100 lbs. for lime. Both these costs included the cost of delivery. Supplies and maintenance materials for flotation thickeners and vacuum filters in the three treatment plants which used them were costed using the superintendents' cost figures.

Landfill Charges. In all cases where treatment plants disposed of sludge in landfills, a cost of $5/trip to the landfill site was added to the cost of disposal. This was based on the findings that all treatment

plants disposing of sludge in town landfills located in towns other than that in which the treatment plant was located were charged $5/trip for use of the landfill.

5. Per Capita Cost Analysis

One of the primary concerns of this study was to compare the economic costs of the landfill and landspreading methods of sludge disposal in Vermont. The nearly fifty fold difference in design capacities of plants necessitated the expression of disposal costs in terms other than total disposal costs to permit comparison between plants. Cost per unit of design or actual flow could have been used, but it was felt that design flow was not a true reflection of actual flow and actual flow records and estimates were often not accurate or complete. Disposal costs per capita of population served appeared to be the best measure. Plant operators seemed to have accurate estimates on the number of people served by treatment plants. Industrial input to all treatment plants from which cost data were obtained was not large, and it was assumed to be about equal in all cases. Per capita costs of sludge disposal for 17 treatment plants with two plants providing two sets of observations were determined.

Four general methods of sludge processing and disposal were observed. One method was the disposal of liquid sludge by landspreading without dewatering processes being used. Two methods of disposal used sand drying beds to dewater sludge after which sludge was disposed of either by land-spreading or by placing it in a landfill. The fourth method was to dewater

sludge by using flotation thickeners in combination with vacuum filters after which sludge was placed in a landfill. After per capita disposal costs had been calculated for each observation, the observations were grouped by disposal method and an analysis of variance was performed to determine if the per capita disposal costs for any one method were significantly different from those of any other method.

Part of this research was based on the hypothesis that economies of scale existed in sludge disposal operations, that is, as populations served or sludge quantities got larger, it got less expensive per unit of sludge or per capita to dispose of sludge. The analysis of variance performed indicated that two separate populations existed within the nineteen observations of per capita disposal costs. To check the hypothesis that there are significant economies of scale in sludge disposal costs within these two sample populations, a linear regression incorporating the ordinary least squares method was calculated for each using per capita disposal costs as the dependent variable and populations served as the independent variable. The regression equations are of the following form:

$$\frac{TC}{P} = b + m\,P$$

where, TC = per capita disposal costs in 1976 in dollar terms,

P = population served, and

b,m = equation coefficients to be estimated.

6. Transportation Cost Analysis

Research on larger sized treatment plants and treatment plants located in urban areas indicates that transportation costs and distances to

disposal sites were major factors considered in decisions governing sludge disposal location or type (see Bibliography items 3,10,18). Distances from treatment plants to various disposal sites in Vermont varied considerably, from .25 miles to 15 miles for the treatment plants surveyed in this study. Accordingly, it was felt that the effect of distances to disposal sites on total disposal costs for treatment plants in Vermont would be a useful area to investigate further. To determine this effect, cost elasticities of transportation were calculated for all nineteen observations of total disposal costs. The cost elasticity of transportation was defined in this case as the percentage change in total cost divided by the percentage change in the cost of transportation as distance to the disposal site was changed. Algebraically it may be expressed as:

$$\text{cost elasticity of transportation} = \frac{\%\Delta TC}{\%\Delta TrC} = \frac{-\dfrac{TC_1 - TC_2}{\dfrac{TC_1 + TC_2}{2}}}{\dfrac{TrC_1 - TrC_2}{\dfrac{TrC_1 + TrC_2}{2}}}$$

where, TC_1 = total cost of sludge disposal in 1976,

TC_2 = total cost of sludge disposal in 1976 plus the added cost of transportation when distance to the disposal site was changed,

TrC_1 = total cost of sludge transportation in 1976, and

TrC_2 = total cost of sludge transportation in 1976 plus the added cost of transportation when distance to the disposal site was changed.

For purposes of this study, cost elasticities of transportation for added distances of five and twenty miles were calculated. Elasticities were then compared according to type of disposal method used.

To determine the percentage changes in both total costs and transportation costs, certain assumptions had to be made. It was assumed that all sludge disposal vehicles traveled at an average speed of twenty miles per hour. Thus, an added distance of five miles one way to a disposal site would mean an added distance of ten miles round trip for the disposal vehicle and an added use time of one-half hour. Depreciation and overhead expenses on non-rental vehicles were assumed to remain the same when distances to disposal sites were changed, and only operations and maintenance expenses changed in these cases.

Benefit Investigation

This study was concerned with exploring the benefits as well as the costs of the landfill and landspreading methods of sludge disposal used in Vermont. Many of the benefits were not easily measured in economic terms, and for this reason they were not incorporated in this study. The only measurable benefit of sludge disposal was assumed to be the nutrient addition to soils that resulted from landspreading disposal of sludge. A discussion of other benefits of both landfill and landspreading disposal and the difficulty of measuring these benefits is needed for more complete understanding of the problem. These benefits, the problems of measuring them, and the procedure used for determining the economic value of the nutrients contained in sludges are discussed in this section of the methodology.

1. Benefit of Landfill Disposal

Virtually all of the benefits of the landfill method of disposal were not considered to be measurable in economic terms. There are some distinct benefits, however, that the landfill method has which the landspreading method does not have. Town landfills are usually kept open year round and are accessible at any time for sludge disposal. Also, in most town landfills there is equipment available to bury sludge. Town landfills are usually removed from more densely populated areas of the town, and thus, the perceived or real problems of a large portion of the population coming in contact with the sludge are minimized. There is also the question of the economic value of the landfill contents. Some initial research has been done on the value of the contents of landfills when they are recycled for other purposes, but it has not been conclusive.[5]

2. Benefits of Landspreading

There are several benefits that landspreading has over the landfill disposal method, but again most are not easily measured in economic terms. Some people feel that the landspreading method of disposal is an environmentally sound method of sludge disposal. They employ what has been termed the "living filter" concept as applied to soils and their interactions with sludges (see Bibliography items 1,13,18). Prior research

[5] W. H. Mitchell and G. J. Hendricks, "Using Solid Waste and Plastic Netting for the Production of Cultivated Sod," (Paper presented at the Northeastern Branch Meeting of the American Society of Agronomy, University of Vermont, Burlington, Vermont, June 29, 1977).

has indicated that soils act as a good filter for the pollutants contained in sludges (see Bibliography item 9). The economic benefits of a reduction in pollution are real but extremely difficult to measure and are, therefore, not incorporated in this study.

When sludge is applied in liquid form to cropland, it often provides the benefit of adding a great deal of water to the land. A reasonable application rate of 150,000 gallons per acre of liquid sludge containing five per cent total solids would add over five inches of water to the soil. This water can be very beneficial, and sludge has been shown to be useful as a source of irrigation water (see Bibliography item 1). It is difficult to put a dollar value on this water in Vermont, however, partly due to the variability of the weather and amounts of rainfall. The variability of costs of irrigation systems and the economic feasibility of installing them also make the value of sludge irrigation water difficult to measure.

A very large benefit of sludge disposal by the landspreading method of disposal is the conditioning effect that sludge has on the soil (see Bibliography items 2,4,5). Sludge adds organic matter to the soil. Organic matter in soils increases the water holding capacity of the soil. It also improves soil aeration and soil structure. These are valuable properties. Putting an economic value on them is difficult. Part of the difficulty in measuring the soil conditioning benefit lies in the variability of soils themselves. Addition of sludge to a heavy clay soil deficient in organic matter may have a greater benefit than addition of the same sludge to a sandy loam already high in organic matter. In

addition, the economic value of additional organic matter in soils will vary with the types of crops being grown, the cultivation practices, and even the weather. As yet no satisfactory economic measure of the soil conditioning effects under these varying conditions exists. For this reason the economic benefits of sludge as a soil conditioner were not considered in this study.

3. Value of Nutrients Contained in Sludges

The benefit that exists and which can be measured and evaluated economically with some accuracy is the nutrient addition to soils when landspreading is used as a disposal method. A close determination of amounts of nitrogen, phosphorus, potassium, and other micronutrients present in sludges can be obtained through chemical analysis. By determining an economic value for these plant nutrients, a value of the nutrient content of the sludges may also be calculated. The micronutrients available in sludge, while important, are not a major economic benefit since they are usually present in the soil in sufficient quantities for crop growth. The addition of nitrogen, phosphorus, and potassium to soils was the only benefit of sludge disposal by the landspreading method which this study attempted to measure.

4. Nutrient Values of Commercial Fertilizers

The nutrient values of nitrogen, phosphorus, and potassium were computed from fertilizer price information supplied by a local retailer of

commercial fertilizer.[6] Prices of commercial fertilizers from 1968 to 1977 were obtained. The 1976 retail values of nitrogen, phosphorus, and potassium contents were based on the 1976 prices of urea (45 per cent nitrogen), concentrated super phosphate (44 per cent P_2O_5 and, therefore, 19.2 per cent phosphorus), and muriate of potash (60 per cent K_2O and, therefore, 49.8 per cent potassium).

5. Nutrient Contents of Sludges

Only three treatment plant operators interviewed had knowledge of the amounts of nutrients in the sludges coming from their treatment plants, and in these cases the information was not felt to be entirely accurate. Amounts of nutrients per dry weight of sludge used in this study were based on two sources. Dowdy, Larson, and Epstein analyzed over 200 sludges coming from eight midwestern states. The range and median values that they found for nitrogen, phosphorus, and potassium are given in Table 3.[7] In addition, the nutrient contents of sludges from three treatment plants in Vermont, two of which were cases considered in this study, were under investigation by the Plant and Soil Science Department at the University of Vermont at the time of this study. Unpublished findings for sludges from two of these treatment plants give average nitrogen contents of 6.85 per cent and 5.49 per cent, phosphorus contents

[6] William B. Clark, Regional Fertilizer Product Manager, Fertilizer-Chemical Division, Agway, Inc., Bos 1333, Syracuse, New York, 13201.

[7] R. H. Dowdy, R. E. Larson, and E. Epstein, "Land Application of Waste Materials," (Ankeny, Iowa: Soil Conservation Society of America, n.d.), p. 313.

TABLE 3

RANGES AND MEDIAN VALUES

FOR NITROGEN, PHOSPHORUS, AND POTASSIUM CONTENTS

OF SAMPLED SLUDGES

Nutrient	Percentage of Dry Solid Equivalents		
	High Value	Median Value	Low Value
Nitrogen	17.6	3.3	<.1
Phosphorus	14.3	2.3	<.1
Potassium	?.0	0.4	.02

of 2.01 per cent and 2.15 per cent, and potassium contents of 1.21 per cent and .65 per cent. These findings fell well within the ranges found by Dowdy, Larson, and Epstein and were felt by the researchers examining them to be representative of the sludges coming from wastewater treatment plants in Vermont.

Values of 5 per cent for nitrogen, 2 per cent for phosphorus, and 1 per cent for potassium of dry weights of sludges were used for purposes of this study to determine the economic benefits resulting from the land-spreading method of sludge disposal. A more accurate determination of benefits of sludges coming from each treatment plant would require that sludge from each plant be analyzed separately. Nutrient values of sludges will vary in each plant depending on a number of factors including the characteristics of the wastewater being treated, the types of treatment it receives, the age of the sludges being tested, and the chemical or polymer conditioners, if any, which may have been added to the sludges.

It was assumed that all the nutrient amounts in the sludges that were examined would eventually become available to crops being grown on the disposal sites. There are problems inherent with this assumption. Sludge handling and landspreading methods will greatly affect the amounts of nutrients in sludges that become available to plants being grown on the disposal sites. The amount of nutrient loss, especially in the case of nitrogen, will vary greatly. Sludges dewatered on drying beds may have a greater nutrient loss than those dewatered on vacuum filters or those applied in liquid form. Cultivation practices will also affect the loss of nutrients. Sludges which are injected below the surface or which are

plowed under immediately after spreading will likely have a smaller nutrient loss and greater nutrient availability than those sludges which are spread on the ground surface and not plowed under. Time of application during the year is also important and will affect nutrient loss. The type of soil will affect nutrient availability and release schedules as well. All of these factors make the potential nutrient benefits of sludges biased toward high estimates.

6. Determination of the Economic Values of Sludges

The dry solids equivalents of sludges produced in the wastewater treatment plants for which total costs of disposal had been determined had been estimated by researchers in the Water Resources Department at the University of Vermont. These estimates, based on types of wastewater treatment and populations served, were used for determination of the potential economic benefits to be gained from the nutrients contained in sludges produced in these seventeen treatment plants. Here again, however, a great deal of caution must be exercised. These estimates are based on the number of people served by the treatment plant and the type of treatment plant. Actual amounts of sludge produced per person even in treatment plants with the same facilities for treating wastewater will vary greatly. Variation in seasonal flows due to the weather, design in combination with actual use flows into the treatment plant, in-plant practices, and operator experience are some of the factors which will affect the amount of dry solids equivalents of sludge actually produced. There was some evidence that these estimates used were high. This would pro-

duce further upward bias in the potential benefits of landspreading sludge.

Determination of the economic value per pound and per ton of sewage sludge were calculated using the retail values of nitrogen, phosphorus, and potassium and the assumed percentages of these nutrients in sludge. The economic value of sludges produced in each treatment plant were then determined using the estimates of dry solids equivalents of sludges produced in each of these treatment plants.

7. Comparing Costs and Benefits

The potential benefits of sludge were felt to be large and their effects on disposal decisions could not be ignored. In addition to the cost-effectiveness analysis, what might be called a benefit-effectiveness analysis was performed. As in the case with costs, these benefits were evaluated in terms of total potential community benefits to be gained, not just potential benefits to be gained by individual recipients of sludge. This was done by calculating ratios comparing potential economic values of the nutrients contained in sludges to the total disposal costs in each treatment plant from which data on costs and benefits was available. These ratios were by no means considered to be benefit-cost ratios in the traditional sense. Since not all of the seventeen treatment plants used landspreading as a disposal method, the ratios as a whole were not meant in any way to indicate benefit-cost relationships. They did, however, serve to point out what portion of 1976 disposal costs would have been deferred if the potential nutrient benefits of sludges had been paid for.

It is realized that adjustments would have to be made on these ratios if disposal methods were changed to facilitate this type of cost recovery. This analysis would have to be done on an individual plant basis taking into account closer approximations of total dry solids equivalents produced, actual sludge nutrient contents, and the expected disposal cost chagnes which would occur from changes in disposal methods. Adjustments would also have to be made in the event of commercial fertilizer price changes.

Influences on Disposal Decisions

During the interviews with treatment plant operators, a great deal of information was gathered concerning factors which might influence disposal decisions. It had not, however, been captured in the previous analyses. The questionnaire design did not lend itself to a statistical analysis of this type of information. A subjective discussion of some of the factors which seemed to have considerable influence on the choice of disposal method appeared to be the best approach to this problem. Enumeration of cases and specific examples were used when possible to strengthen arguments presented.

Landspreading Attitudes and Land Availability Investigation

It was felt that more than just the benefit and cost information and other primary information gathered from the treatment plant operators had to be considered for purposes of this study. To obtain a better understanding of the landspreading methods of sludge disposal used in Vermont

and the potential for increased landspreading, two additional questionnaires were developed. The first, entitled "Questions for Users" (see Appendix 3), was used in seven interviews with users of sewage sludge in Vermont. The second, entitled "Questions for Non-Users" (see Appendix 4), was used in five interviews with farm operators who had not used sludge but were in close proximity to the treatment plants under consideration.

The User questionnaire was designed to give indications as to the extent people were using or had used sludge and the amount of effort and cost they expended to obtain the sludge. It sought to find the intensity of sludge use and the variety of sludge application techniques. How much users knew about the sludge they were using, what they knew of regulations governing its use, and what precautions were being taken in sludge application were areas investigated. Values placed on sludge by users was sought. The Non-User questionnaire sought information concerning knowledge about sludge, willingness to use sludge, and types of land near to treatment plants available for sludge disposal.

The number of users and non-users sampled was small. A great deal of information was gathered from this small sample, however, showing the variability that exists with respect to attitudes toward sludge, sludge application practices, and the crops on which sludge was used. No statistical analysis was performed on the data gethered by use of the user and non-user questionnaires. The information was simply compiled and presented.

Regional Disposal Exploration

The final objective of this study was the development of a method and .inancial scheme for a regionalizeu approach to sludge disposal in Vermont. Problems involved with the recycling of waste materials and in organizing regional efforts have been discussed by others, and this information provided useful background information and techniques for implementing regional plans (see Bibliography items 2,8,11,15,17). Information gathered throughout the course of this investigation pointed out problems even more specific to Vermont with respect to regional efforts, and these were discussed. This investigation, however, had also turned up evidence of considerable regional efforts in sludge disposal that had already been implemented. This evidence was also presented.

In light of the information gathered and analyses performed, the feasibility of increased regional efforts was felt to exist, and one regionalized approach to sewage sludge disposal was formulated on the basis of this information. This regional plan, while subjective in nature, attempted to apply the findings of this study to problems of sludge disposal in Vermont.

COST ANALYSES

Total and Per Capita Sewage Sludge Disposal Costs

Both total disposal costs and per capita disposal costs were calculated for seventeen of the wastewater treatment plants sampled with two treatment plants supplying two sets of costs for two different methods of disposal. Four methods of processing and disposal were observed. Table 4 presents the nineteen calcualtions of total costs and per capita costs categorized by sludge processing and disposal method.

Analysis of Variance on Per Capita Disposal Costs

In order to determine if any of the four methods of processing and disposal were significantly different from each other in terms of per capita sludge disposal costs, an analysis of variance was performed on the per capita disposal costs categorized by these four methods:

Case A. Dewatered on sand drying beds and disposal in landfills.

Case B. Dewatered on sand drying beds and disposal by landspreading.

Case C. Disposal by liquid landspreading.

Case D. Dewatered using flotation thickeners in combination with vacuum filters and disposal in landfills.

Table 5 presents the analysis of variance results for the per capita costs of disposal for the four methods and contrasts among mean per capita costs for specific processing and disposal methods. Critical F values greater than 3.68 and 5.42 were needed to reject the null hypotheses at the .05 and .01 levels of significance, respectively.

TABLE 4

TOTAL AND PER CAPITA ANNUAL COSTS OF SLUDGE DISPOSAL IN 1976

Processing and Disposal Method	Total Sludge Disposal Costs	Per Capita Sludge Disposal Costs
Sand Drying Beds and Landfill Disposal	$ 2,633	$ 1.76
	1,653	.61
(CASE A)	703	.40
	1,942	.67
	2,984	2.49
	3,061	1.02
	1,726	1.15
	6,091	2.44
	2,764	.46
	2,669	.42
Sand Drying Beds and Landspreading Disposal	1,048	1.40
	2,084	.69.
(CASE B)	4,650	1.55
Liquid Landspreading Disposal	5,883	1.96
(CASE C)	1,392	.56
	5,015	.68
Flotation Thickeners With Vacuum Filters and Landfill Disposal	105,587	4.22
	42,753	4.75
(CASE D)	34,833	6.97

TABLE 5

ANALYSIS OF VARIANCE ON PER CAPITA SLUDGE DISPOSAL COSTS

Source	Degrees of Freedom	Sum of Squares	Mean of Squares	F-Ratio*
Between Groups	3	44.08509	14.6950	18.7440*
Within Groups	15	11.75979	.783986	
Total	18	55.84488		
Contrasts Among Disposal Method Means				
A, B, and C, vs. D		44.0601		56.2*
B and C vs. A		.0042		.001
A vs. B		.0070		.009
A vs. C		.0134		.017
B vs. C		.0257		.03

* Denotes significance at the .01 level.

The null hypothesis stating that there were no differences among the mean per capita disposal costs for the four methods of processing and disposal was rejected at the .01 level of significance since an F value of 18.7440 was obtained for the analysis of variance. Contrasts among the per capita disposal cost means indicated that the per capita disposal cost mean for method D, processing by flotation thickeners in combination with vacuum filters and disposal in landfills, was significantly different from the rest of the per capita disposal cost means at the .01 significance level. That is to say that from this analysis of variance based on nineteen observations of per capita costs, there was sufficient evidence at the 99 per cent confidence level to suggest that the mean per capita cost associated with sludge processing by flotation thickeners and vacuum filters and disposal in landfills was significantly different from the rest of the average per capita disposal costs associated with the other three processing and disposal methods observed.

Further contrasts of per capita disposal cost means for the other three methods of processing and disposal indicated that there was no significant difference among per capita costs associated with these methods. The null hypothesis stating that there was no significant difference among per capita disposal costs associated with these three methods, sand drying bed dewatering and disposal in landfills, sand drying bed dewatering and disposal by landspreading, and liquid landspreading, could not be rejected.

Per Capita Disposal Costs Related to Populations Served

To see if there was any significant relationship between per capita disposal costs and populations served by treatment plants for each of the two sample populations indicated by the analysis of variance, linear regressions incorporating the ordinary least squares method were calculated for each of the two sample populations. Per capita disposal costs were used as the dependent variables and populations served by the individual treatment plants as the independent variables for both samples. The null hypotheses in each case was that there was no linear relationship between per capita costs of sludge disposal and populations served by the treatment plants. Another way of stating this is:

$$H_o : m = 0$$

where m is the estimated slope of the regression line. The alternative hypothesis is that the actual linear relationship between per capita disposal costs and populations served is non-zero:

$$H_A : m \neq 0$$

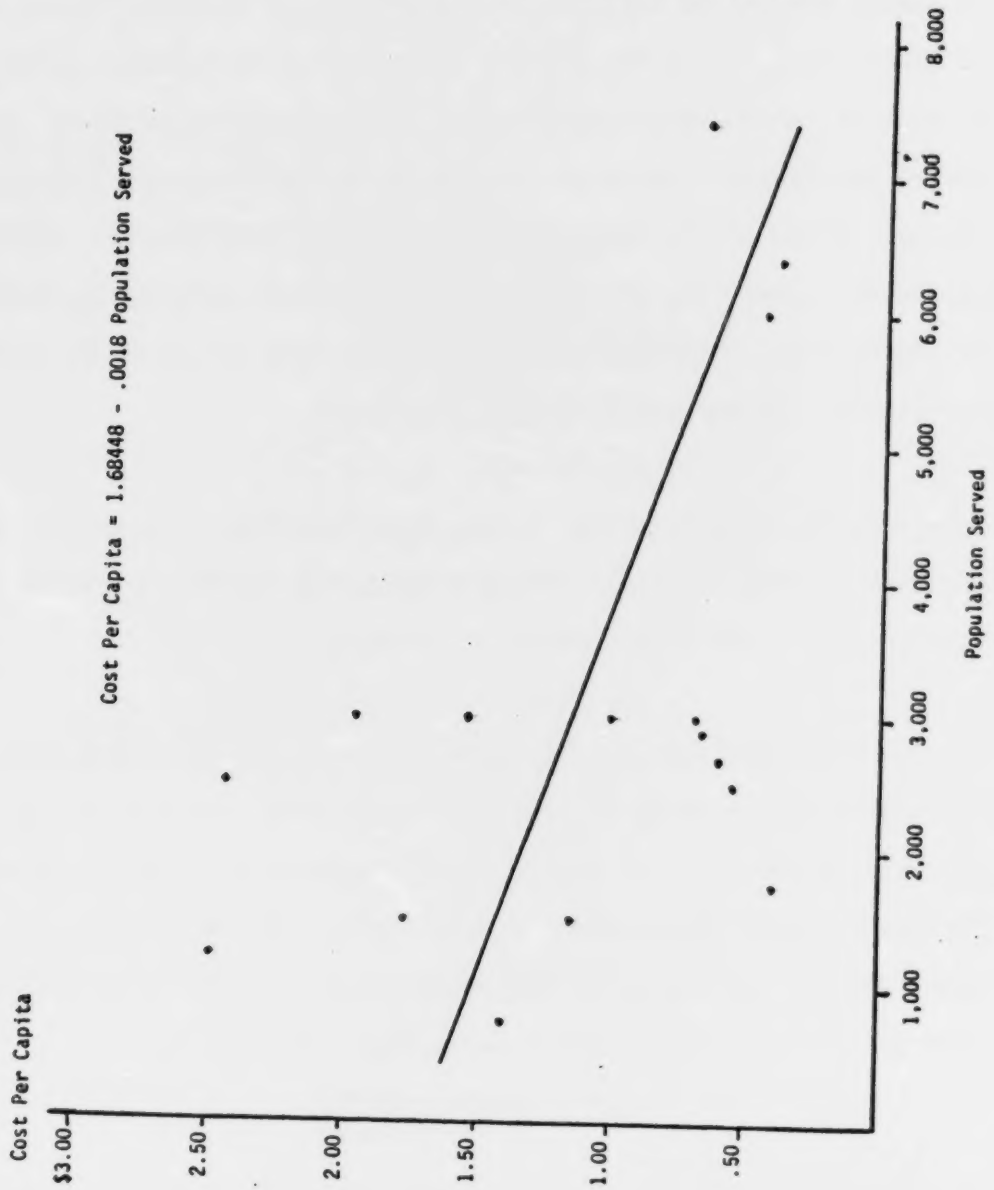
The first sample population included those treatment plants which used liquid landspreading of sludge and those which used sand drying beds to dewater sludge prior to later disposal in landfills or by landspreading. There were sixteen observations in this sample. Figure 3 shows a plot of these variables and the calculated regression line. The calculated regression equation, with t-value in parentheses, was:

$$\frac{TC}{P} = 1.68448 - \underset{(2.022)}{.00018}\ P$$

The estimated t value was not large enough to permit rejecting the null hypothesis at the .05 level of significance. The low r^2 value, .226,

FIGURE 3

Linear Regression on Per Capita Sludge Disposal Costs
Associated with Liquid Landspreading and Sand Drying Bed Dewatering
Prior to Landfill and Landspreading Methods of Sludge Disposal



indicated that a little less than 25 per cent of the variation in per capita cost was explained by the variable population. This suggests that there were other variables explaining a large portion of the variation in per capita disposal costs which were not identified.

The regression analysis performed on the sample population of treatment plants which used vacuum filters and flotation thickeners to process sludge before disposal in landfills had only three variables. A plot of these variables and the calculated regression line for this case is found in Figure 4. The regression for this sample was:

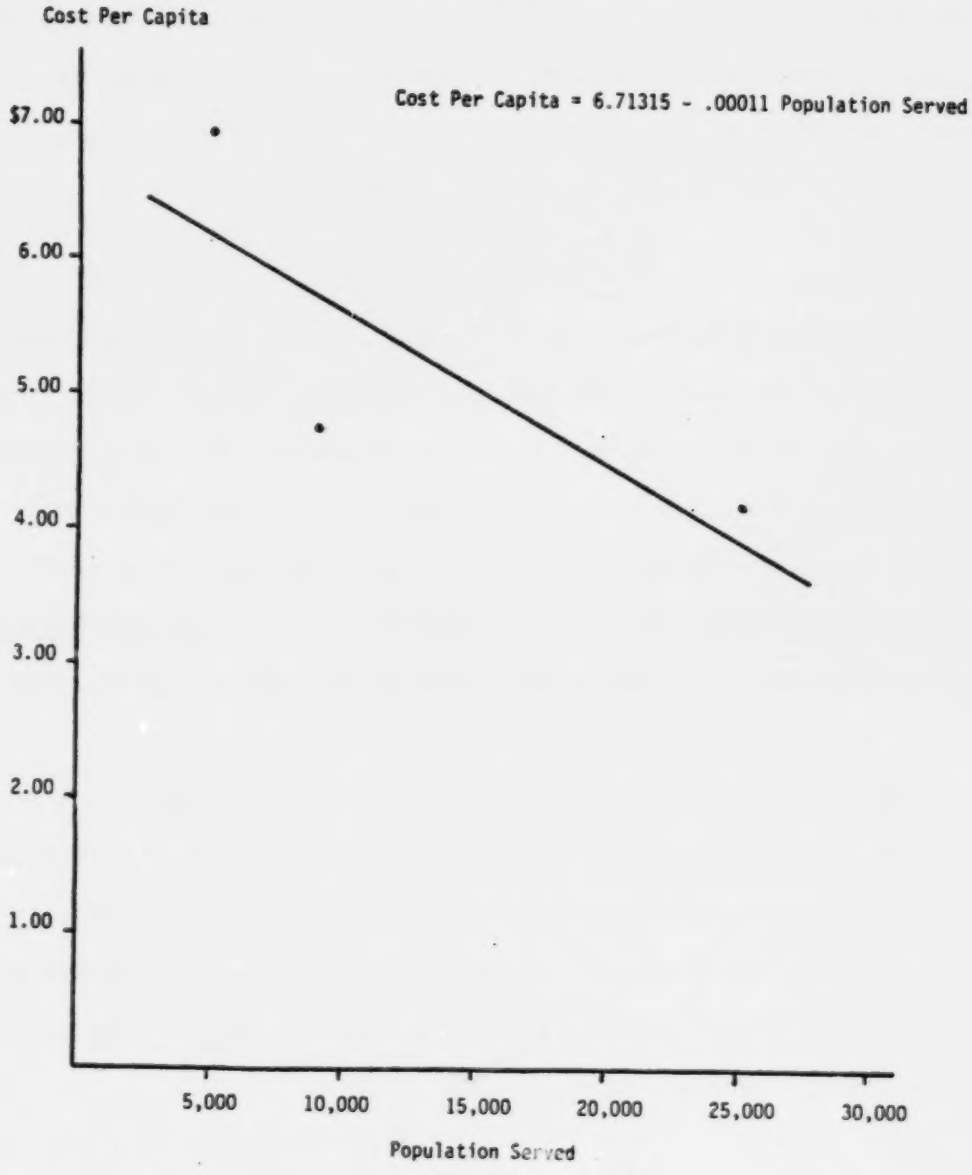
$$\frac{TC}{P} = 6.71315 - \underset{(1.251)}{.00011}\ P$$

The estimating equation had an r^2 of .610. Again the null hypothesis could not be rejected at the 0.5 level of significance. The very small sample size in this case should caution one against any generalizations. A relatively high r^2 value indicated that about 61 per cent of the variation in per capita sludge disposal cost had been explained linearly by the variable population. The variation in per capita disposal costs to be explained by variables other than populations served was less than 40 per cent.

Neither of the sample populations indicated any significant linear relationship between per capita disposal costs and size of population served by treatment plants at the 95 per cent level of confidence. Graphical representations of the data and regression lines showed an inverse relationship between per capita costs and size of populations served in both groups.

FIGURE 4

Linear Regression on Per Capita Disposal Costs
Associated with Flotation Thickeners and Vacuum Filters
and Disposal in Landfills



Cost Elasticities of Transportation

The cost elasticities of transportation for the nineteen observations were all inelastic due to the nature of the equation. Relative magnitude of the elasticities indicate the impact upon costs of additional distances to disposal sites. When a five mile distance was added to the disposal sites, the elasticities ranged from .017 to .706 with a mean value of .256. For an additional distance of twenty miles, the ratios ranged from .041 to .806 with a mean value of .305. The greater the distances traveled, the less inelastic the ratios became. That is, the greater the distances the more responsive total costs became to transportation costs.

Elasticities were then compared according to type of processing and disposal method. Table 6 shows the cost elasticities of transportation for the nineteen observations categorized by type of processing and disposal method when added distances of five and twenty miles were considered. Mean values for categories are indicated.

When the mean values of the cost elasticities of transportation for liquid sludge disposal were compared to those for sludges dewatered on sand drying beds, they were observed to be at least four times as large. Although two of these three categories have few observations, this comparison would seem to indicate that the total costs of disposal were much more responsive to transportation costs and distances to disposal sites for this sample population when sludge disposal was in liquid form than when sludge had been dewatered on sand drying beds prior to disposal. During liquid disposal larger volumes of water are being transported along

TABLE 6

COST ELASTICITIES OF TRANSPORTATION

Type of Processing and Disposal	5 Miles Added Distance	20 Miles Added Distance
Dewatered on Sand Drying Beds and Disposal in Landfills	.252	.339
	.085	.114
	.017	.041
	.087	.172
	.156	.228
	.102	.114
	.175	.189
	.053	.099
	.132	.207
	.081	.103
	$\bar{M}_5 = .114$	$\bar{M}_{20} = .161$
Dewatered on Sand Drying Beds and Disposal by Landspreading	.142	.194
	.072	.104
	.027	.052
	$\bar{M}_5 = .080$	$\bar{M}_{20} = .117$
Disposal by Liquid Landspreading	.589	.699
	.706	.781
	.675	.806
	$\bar{M}_5 = .648$	$\bar{M}_{20} = .762$
Flotation Thickeners, Vacuum Filters, and Disposal in Landfills	.452	.519
	.444	.507
	.459	.532
	$\bar{M}_5 = .452$	$\bar{M}_{20} = .519$

with the waste product, thus increasing transportation costs. Also, total processing costs in these cases have been reduced because the sludge is essentially not processed at all. Cost elasticities of transportation for sludges dewatered by flotation thickeners and vacuum filters and disposed of in landfills were observed to be higher than those for sludges dewatered on sand drying beds and lower than those for liquid sludge disposal.

BENEFIT ANALYSIS

The 1976 retail prices per ton for urea, concentrated super phosphate, and muriate of potash were $177.00, $118.56, and $112.40 respectively. The cost of the nutrients in 1976 based on these fertilizers was therefore $.197 per pound for nitrogen, $.309 per pound for phosphorus, and $.113 per pound for potassium. Sludges which have assumed values of 5 per cent nitrogen, 2 per cent phosphours, and 1 per cent potassium had an economic value of $.0172 per pound ($34.60 per ton) of dry solids equivalents in 1976 based on the value of the nutrient contents in that year.

Table 7 shows the estimated amounts of sludges produced per day and per year for the nineteen observations for which disposal costs had been calculated. It also gives the maximum economic value of the nutrients contained in these sludges for the year 1976, the total costs of disposal in 1976, and the ratios comparing the potential benefits of the sludges to the total costs of disposal. The nineteen observations are again catagorized by sludge processing and disposal method.

The ratios comparing potential economic benefits to total costs of sludge disposal in 1976 ranged from .13 to 3.52. This points out that the maximum potential value of sludges coming from these treatment plants, had the sludges been used as a fertilizer source, ranged from 13 per cent to 352 per cent of the total actual disposal costs in that year. For the six observations of sludge disposal which actually used landspreading as a disposal method, the range of the ratios comparing potential benefits

TABLE 7

AMOUNTS OF SLUDGE PRODUCED AND POTENTIAL BENEFITS COMPARED TO TOTAL COSTS OF SLUDGE DISPOSAL IN 1976

Dry Solids Equivalents Produced		Total Nutrient Value	Total Costs of Disposal	Ratio of Benefits to Costs
Lbs./day	Lbs./year			
Sand Drying Beds and Landfill Disposal				
351	128,115	$ 2,216	$ 2,633	.84
608	221,920	3,817	1,652	2.31
394	143,810	2,473	703	3.52
653	238,345	4,100	1,942	2.11
168	61,320	1,055	2,984	.35
420	153,300	2,637	3,061	.86
104	37,960	653	1,726	.38
350	127,750	2,197	6,091	.36
450	164,250	2,825	2,764	1.02
896	327,040	5,625	2,689	2.09
Sand Drying Beds and Landspreading Disposal				
169	61,685	1,061	1,048	1.01
675	246,375	4,238	2,084	2.03
675	246,375	4,238	4,650	.91
Liquid Landspreading Disposal				
675	246,375	4,238	5,883	.72
350	127,750	2,197	1,392	1.58
1,036	378,140	6,504	5,015	1.30
Flotation Thickeners with Vacuum Filters and Landfill Disposal				
3,500	1,277,500	21,973	105,587	.21
1,260	459,900	7,910	42,753	.19
700	255,500	4,395	34,833	.13

to total disposal costs was from .72 to 2.03. Assuming that the maximum potential value of the nutrients in the sludges had been obtained and utilized as a fertilizer source, this meant that 72 per cent to 203 per cent of the sludge disposal costs were recovered using landspreading methods of disposal.

It was observed that the lowest ratios comparing potential benefits to disposal costs were found for treatment plants using flotation thickeners and vacuum filters prior to landfill disposal. While the ratios were lowest for these treatment plants, the actual total value of the sludges coming from these treatment plants was considerable because of the large volumes produced. The economic impact of a change to land-spreading disposal, especially for these treatment plants producing large volumes of sludge, was considered to be very significant.

Prices of fertilizers between 1974 and 1975 went up drastically. Urea and concentrated super phosphate increased in price 85 per cent and 39 per cent, respectively. This percentage increase in price, had it occurred between 1976 and 1977, would have increased the value of a ton of sludge from $34.60 to $56.22, an increase of 63 per cent. This points out that increases in prices of commercial fertilizers similar to those experienced in the past would also greatly increase the value of sludge as a fertilizer source.

OTHER FACTORS INFLUENCING DISPOSAL DECISIONS

During the interviews with treatment plant operators, a great deal of information was gathered concerning other factors which might influence disposal decisions. This section discusses some of the factors which seemed to have considerable influence on the choice of disposal methods.

Plant Design

The area of greatest concern expressed by operators in this sample appeared to be the operation and maintenance of the sand drying beds. Ten of the fifteen operators interviewed who had drying bed facilities had major complaints. Most of these complaints centered around the inefficiency of the drying beds due to inadequate size, lack of covers, or high water tables on which the drying beds had been built. Two operators who had covered drying beds felt the covers required forced ventilation that had not been provided. There were also complaints that drying beds could not be used in the winter. Some operators felt that they were both messy and costly to operate and maintain. Inefficient drying beds had, in some cases, cost operators much added time, resulting in increased expense to the towns. Problems with drying beds had caused several operators to change to liquid sludge disposal.

Lack of liquid outlets reduces the flexibility of sludge disposal operations by making the options of liquid sludge disposal in these cases more difficult and costly to accomplish. Not all treatment plants had

incorporated within their design the capacity to put sludge out in liquid form. This seemed to be consistent even in the newer treatment plants. One new plant in the Northern area was having a dual-cell dewatering device installed in it, yet it did not have the built-in ability to pump liquid sludge out of the aerobic sludge digestor tanks to any other outlet. The inclusion of this option would have required the installation of no more than twenty feet of pipe with two or three elbows and hangers in a treatment plant costing over two million dollars. The marginal cost of including this option would have been almost negligible, and certainly much less than the potential benefits to its operation.

Plant Operator Initiative and Experience

The disposal methods chosen by an operator seemed to lie in large part on each operator's own initiative and experience. Some operators were motivated to cut costs, others were not. In several cases reduced plant man-hours and/or contact-hours with the sludge during the disposal operations were of greater importance than minimizing operating costs.

Many operators experimented with both in-plant and disposal operations trying several methods in order to increase efficiency. The achieved efficiencies were not always reflected in reduced total economic costs of disposal, but often resulted in reduced costs to the towns. In several cases, operators contacted potential users of sludge and informed them of its value and availability. Many operators removed sludge for their own use, and one of these operators removed all the sludge produced at his treatment plant for his own use. Some operators prepared the sludge at

the treatment plant for other people to pick up. Others devised home-made vehicles to take liquid sludge to users.

Cost Records

In only a few cases were easy and accessible cost records kept at the treatment plant. Some operators had rough ideas of various costs, but many did not seem to have even rough estimates. If costs are to be a major consideration in sludge disposal decisions, accurate cost records, particularly the costs of disposal operations, are a prime prerequisite for making disposal decisions.

Weather

Weather played a large part in sludge disposal decisions in Vermont. Drying beds often worked less efficiently in wet years and required more maintenance and adjustment of disposal schedules. Often times sludge that was ready for disposal would get rained on and need additional drying time and work effort to get it ready for disposal again.

Of the three cases where liquid sludge disposal had been used, two had experienced problems that were related to the weather. Wet springs and the inability to get on fields had caused each operator in these two treatment plants to resort to use of their drying beds. Most treatment plants had to store sludge through the winter. By spring the sludge holding capacities of treatment plants are usually minimal, and sludge must be transferred, or "wasted," to another area. In these two cases, the small holding capacities in combination with the weather forced the

operators to "waste" sludge to their drying beds instead of to liquid sludge disposal vehicles, thus limiting their disposal options. With dryer weather or an increased holding capacity they could have waited and disposed of sludge in liquid form.

Environmental Problems and Considerations

One objective of this study was to determine how much consideration to the environment was given by treatment plant operators in the practice of sludge disposal. The questionnaire was found not to be fully adequate for these purposes. Any attempts at this time to quantify the amount of environmental consideration given by treatment plant operators might result in unfair speculation and generalizations. The survey did indicate, however, some of the environmental problems and concerns that treatment plant operators had as well as some strong indications of potential problems in this area.

Sludge odors was the most frequent environmental problem encountered by treatment plant operators. Over half the treatment plant operators surveyed reported having received complaints from homes in neighborhoods adjacent to the treatment plant or to the disposal site being used.

Of those treatment plants disposing of sludge in landfills, most were using state approved landfills. Three treatment plants, however, indicated that they were disposing of sludge in landfills which were not state approved. Four treatment plants surveyed were being subjected to pressure from the state to change their disposal sites due to environmental concern. Sludges in the landfills were sometimes buried immediately and other times not buried for long periods of time.

Of the three treatment plant operators who were disposing of sludge by liquid landspreading, two said the disposal sites were state approved, and one said he didn't know if the site he was using was approved or not. Dewatered sludge had at times been given to anyone who wanted it without any knowledge as to where it would be spread.

Advice given by treatment plant operators to users of sludge about potential health hazards that might be involved ranged from heavy precautions to none at all. Some treatment plants did not allow private removal. Some operators were careful to forewarn people that sludge should not be used on vegetables. In at least one case, the operator used sludge on his own garden. One treatment plant took the precaution of having all people who received sludge sign a paper declaring that the town was not responsible for adverse effects resulting from sludge use.

These observations help to point out the diversity that exists among treatment plant operators in their attitudes toward sludge and its potential effects on people and the environment. These attitudes, in individual cases, might also influence the choice of one disposal decision over another.

USER AND POTENTIAL USER INFORMATION

To obtain a better understanding of the landspreading methods of sludge disposal used in Vermont and the potential for increased landspreading, seven users and five non-users of sludge were interviewed using interview questionnaires (see Appendices III and IV). The non-users were dairy farmers in close proximity to wastewater treatment plants. The users were dairy and truck farmers who were using or had used sludge. Although the number sampled was small, a great deal of information was gathered showing the variability that exists with respect to many aspects of sludge use. The more important of these are discussed below.

Motivations for Using Sludge

Among non-users of sludge there were both strong negative and strong positive prejudgements concerning sludge and its use. One potential user was very fearful of sludge and felt his cows would not eat corn grown on it. Two non-users were very interested in using sludge. One of these two had tried to obtain some sludge previously but had been unable because the treatment plant near him was unprepared for landspreading disposal methods. Of the people using sludge, none were negative in their attitudes and some had very positive things to say about it.

Some users were motivated only by a sense of social responsibility in that they were allowing it to be spread on their land as a favor to the town. They essentially had no economic motives. Others were using sludge for economic reasons. One user had driven his own five cubic yard dump-

truck a distance of sixteen miles to a treatment plant on eight different occasions to pick up sludge. He initiated this practice "when the price of fertilizer went up." One user was using sludge to condition a sandy soil field on his farm. Another was using it to help "build up" some old fields that had not been tilled for several years to bring them back into production. One user felt the only economic value of sludge was in the water that it contained.

Application Schedules and Methods, Soils, and Crops

Liquid sludge had been hauled and spread by a town-owned truck on which a 2,000 gallon tank had been permanently mounted, by a town-owned dump truck with a 3,000 gallon tank chained to the body, by a farmer-owned flatbed truck with a 1,000 gallon tank temproarily mounted on it, and by a farmer-owned tractor which pulled a 500 gallon tank mounted on truck axles. Dewatered sludge was transported to landspreading sites in both plant and user owned dump and pickup trucks. Interviews with plant operators had also indicated that other people had obtained sludge from the treatment plants in their cars using bushel baskets and plastic garbage bags.

Of those people interviewed, none had applied sludge to cropland during the winter months. Liquid sludge had been spread in the spring, summer, and fall. In some cases the liquid sludge was plowed under but most often was not. It was usually spread before planting, but had been applied between first and second cuttings of hay and on oats which had already emerged. Liquid sludge had also been spread on a no-till corn

planting. Dewatered sludge was usually applied in the spring and plowed under prior to planting.

A variety of both the soils on which sludge was applied and crops which were grown on sludge treated land was found to exist. Users described soils as sandy, sandy loam, silt loam, rocky loam, shale loam, and clay. Crops grown on these soils included corn, hay, and oats. In addition, pumpkins, tomatoes, and cut flowers were grown on sludge treated land and sold in roadside stands. Plant operator interviews revealed that people had used sludge on home lawns and gardens.

Willingness to Pay for Sludge

Several users had already invested capital in their own sludge hauling equipment and paid for the operation and maintenance of this equipment. At one treatment plant a user had installed an elaborate liquid disposal outlet using over thirty feet of six inch cast iron pipe, cast iron elbows, a valve, and angle iron braces. Several users had invested considerable amounts of their own time. One potential user indicated that he would invest time but no money. Another potential user said he would pay "a dollar a load more than the next highest bidder" for sludge.

Problems with Sludge Use

The major complaints from users of sludge, who used their own equipment, was concerned with the time involved in obtaining and spreading sludge. Both those who had hauled the sludge themselves and those who had it delivered commented that when they needed the sludge the most,

usually in the spring before planting, they were also the busiest and could least afford the time. Timing of sludge application to them was critical. One farmer said that he could not allow more than two days leeway for sludge to be delivered to him. There was one complaint of soil compaction from a tank truck application, and one farmer said there was not enough sludge at his local treatment plant to make it worth his efforts to continue to draw sludge.

Several farmers had received complaints about odors from their neighbors after applying sludge, but these complaints did not seem to bother the farmers. In two cases, neighbors were concerned that their health might be affected by the sludge. In both of these two cases, treatment plant operators talked to the neighbors and assured them that the sludge was not dangerous.

SLUDGE DISPOSAL: A REGIONALIZED APPROACH

This study had as one objective the development of a method and a financial scheme for a regionalized approach to sludge disposal in Vermont. The hypothesis was that small treatment plants might gain economies of size by grouping together to dispose of sludge. There were findings in this study which seemed to indicate that regional efforts had already begun in sludge disposal. Increased efforts of this sort were felt to have potential for solving some individual and collective treatment plant problems, particularly in the more densely populated areas such as the Burlington area. This section looks at some of the major difficulties in organizing regional efforts, regional efforts to date, and one approach which was felt to have potential for solving problems for many areas of Vermont through regional efforts in sludge disposal. This regionalized approach attempts, as well, to help fulfill the perceived need for a fuller utilization of resources by all of society through the use of sludge as a fertilizer source.

Problems of Regionalization in Vermont

The greatest obstacle to regionalized efforts in Vermont is probably the basic political unit in Vermont, the town government itself. Historically in Vermont, towns have remained independent and attempted to solve their own problems. This has changed somewhat throughout the years as witnessed by the union school system, but by and large it still remains.

There is no strong intermediate political or organizational unit, such as a county government, to organize and direct a regional effort. When federal wastewater regulations are imposed on Vermont towns, each town alone faces the problem of cleaning up its wastewater and disposing of its sludge. There seems to be no effective means of communication or central forum by which Vermont wastewater treatment plant operators can exchange information and experience each other's problems or successes in dealing with the problems.

Another problem with regionalized sludge disposal operations is the fact that most treatment plants are disposing of relatively small amounts of sludge and are located substantial distances from one another. Some treatment plants are already disposing of sludge in a very cost effective manner and joining in a regional effort could conceivably increase their costs.

Evidence of Regional Efforts

In spite of the above mentioned obstacles, there is some evidence that regional efforts in sludge disposal could be successful and lead to reduced disposal costs for many treatment plants. Regional efforts of sorts and regional sharing of sludge disposal costs have already begun in all three geographic locations chosen for this study.

In the Northern area two of the three treatment plants have tentative plans for using the same landfill disposal site. There is also one plant in the Northern area which has sludge testing and analysis facilities which it plans to make available to other treatment plants.

As indicated previously, an investigation in the Southern area was carried out by the Environmental Conservation Agency of Vermont to determine the expected costs for each of those six treatment plants which would result from the sharing of a commercial sludge disposal vehicle. One of the treatment plants in the Southern area subsequently did purchase one of these transport vehicles and plans on renting it to other treatment plants.

The Burlington area, with eleven treatment plants, has shown the greatest evidence of disposal cost sharing on a regional basis. One landfill accommodates the waste from all three treatment plants in the city of Burlington, and another landfill in Colchester receives or has received the sludge wastes from four other treatment plants located in three different towns in this area. This demonstrates a reduction in the total number of landfills needed for sludge disposal and thus a reduction in capital costs.

One treatment plant in the Burlington area made a tank truck for transporting and spreading liquid sludge by mounting a 2,000 gallon tank on a flatbed truck. This plant has rented the truck to at least four other treatment plants in the Burlington area at a rate of $20 per day.

As a further indication of regionalized efforts in the Burlington area, it is known that plans for a new wastewater treatment plant are under way which would accommodate the wastewater now processed at three of the treatment plants in this area. These treatment plants are located in Colchester, Essex, and Essex Junction Village.

Of the three areas studied, the Burlington area has had the most

experience in regional disposal cost sharing of another sort. This is the sharing of costs by farmers. Two farmers in the Burlington area have hauled large amounts of liquid sludge with their own equipment from treatment plants in this area. At one plant they have combined to remove a full year's worth of sludge. One of these farmers, interviewed as a user of sludge, hauled sludge from two different treatment plants located in two different towns and built a liquid sludge outlet at one plant to enable him to receive liquid sludge.

Regionalized Sludge Disposal: One Approach

Cooperative efforts in rural areas are not new. Christensen discussed the cooperative efforts that farmers have undertaken when faced with various problems and the potential impact on rural communities of a regionalized sludge disposal system (see Bibliography item 1). A potential solution to some of the problems involved with sludge disposal through cooperative efforts of groups of wastewater treatment plants is discussed below. Specific groups and locations of treatment plants have not been identified, but it is felt that this approach would be widely applicable to many areas of Vermont.

One of the problems that many wastewater treatment plants experienced in Vermont was that of being forced to "waste" sludge in the spring when their sludge holding capacities had been reduced to zero. If these treatment plants had a centralized receiving facility, such as a sludge lagoon, they could "waste" sludge at any time of the year. A sludge lagoon of this sort could be an intermediate step between the wastewater

treatment plant and final landspreading disposal. This type of system has the potential for solving other problems as well, as discussed below.

Smaller treatment plants do not have large quantities of sludge available, less than twenty tons of dry sludge per year in many cases. If a number of these plants combined their sludge, the quantity available might become significant and more attractive to farmers as a fertilizer source. Monitoring of sludge landspreading activities would be made easier because sludge would be coming from one intermediate source. Because wasting of sludge to a lagoon could be done from any treatment plant at any time of the year, there would be a greater potential for the sharing of liquid transport vehicles among several treatment plants. This same vehicle could be used, perhaps, to transport sludge to farms and to spread it. Some farmers have liquid manure spreaders that might also be used.

The problem of timing of sludge application would be minimized by this system because sludge being stored in a lagoon could be spread at any time of the year. Farmers could be better guaranteed of sludge availability and application schedules. Contracts with farmers might be arranged. Determination of the nutritive value of sludge would be performed only for sludge coming from the lagoon, not on several sludges from different treatment plants. It would then be easier to determine exactly what the farmer is receiving.

A sludge lagoon storage system might be located nearer to suitable agricultural lands than individual treatment plants are presently located, particularly those treatment plants located in more densely populated areas such as Burlington. Sludge lagoons could be fenced in and placed

acceptable distances from residential areas reducing problems of odor complaints.

An effort to create awareness among farmers of the value of sludge as a soil conditioner and fertilizer combined with an effort to educate the public as to the positive health and environmental benefits of the lagoon system and landspreading disposal could bring very positive results. With increased availability, guaranteed application schedules, and a full comprehension of the values of sludge use, farmers might be more willing to pay for the application of sludge to their land. Some farmers, discussed earlier, have already made considerable investments in sludge application systems.

There are problems inherent with this type of approach. Division of costs of needed land and equipment, purchase or leasing of sludge lagoon sites, schedules for sludge vehicle use and land application, the division of income resulting from the sale of sludge, and gaining public acceptance, as well as the general problems of regional efforts discussed earlier, are a few of the problems that might be encountered. It is felt, however, that these types of problems could be overcome and that this type of approach with its multiple problem solving objectives is needed to make regionalized efforts in sludge disposal a much more attractive option for treatment plants in Vermont.

SUMMARY AND IMPLICATIONS

Sludge disposal had been pointed out to be one of the most difficult problems facing wastewater treatment plants in Vermont, and the problem was seen to be increasing. This study explored the relative economics of the two most commonly used sludge disposal methods in Vermont, landfill and landspreading disposal. Influences other than economic factors on sludge disposal decisions were also examined. The value of sludge as a fertilizer source was determined, and this value compared to disposal costs. In addition, the potential for increased landspreading disposal and regionalized coordination of disposal efforts were explored.

Many problems were presented in undertaking a study of this sort. There was considerable variety found among wastewater treatment plants in Vermont in both their in-plant processing facilities and their disposal procedures. Treatment plants ranged in size from .010 MGD to 4.0 MGD. No means of comparing efficiencies between treatment plants was available. Weather in Vermont played an important part in choice of disposal method and often forced operators to make changes in original plans and operating schedules. The rural locations of treatment plants suggested that distances to disposal sites might be an important economic factor to consider. These problems, coupled with a generally pervasive negative attitude toward sludge, all affected disposal decisions and, ultimately, disposal costs. Major objectives of this project included determining the economic costs and benefits of both the landfill and landspreading

methods of sludge disposal in Vermont. Determining the effect of distances to disposal sites on total disposal costs was a secondary objective. The study also attempted to examine and clarify many of the other factors which might influence disposal decisions.

A questionnaire was developed to obtain data from twenty wastewater treatment plants in Vermont. The survey was carried out during the spring of 1977. Data on the size of treatment plants, populations served, in-plant processing procedures, and disposal methods were obtained. Economic costs of sludge disposal were determined for nineteen observations on the basis of total resources used, not from the standpoint of resources used and paid for directly by the individual treatment plants.

The benefits of both the landfill and landspreading methods of sludge disposal were examined. The only economic benefit of sludge disposal was assumed to be the nutrient value when sludge was disposed using the landspreading method. The nutrient value of sludge was based on the 1976 costs of nitrogen, potassium, and phosphorus in commercial fertilizers and predetermined content of these nutrients in the sludge. Annual values of the sludges produced at treatment plants for which disposal costs had been determined were calculated for 1976 based on estimates of yearly sludge production at these treatment plants. Maximum potential economic values of sludges produced were compared to total costs of sludge disposal to get an indication of the potential for cost recovery through the sale of sludge.

Information gathered during treatment plant operator interviews indicated some specific areas where disposal decisions might be influenced.

Some of these potential influences were perceived to be treatment plant design, initiative and experience of treatment plant operators, weather, cost records kept at the treatment plant, and the environmental concerns of treatment plant operators. These potential influences and how they might affect disposal decisions and costs were discussed. In addition, a small sample of seven current users and five potential users of sludge were also interviewed during the spring and early summer of 1977. These surveys attempted to obtain a better understanding of the landspreading methods being used in Vermont and the potential for increased landspreading.

Four methods of landfill and landspreading disposal were observed. The analysis of variance test performed on per capita disposal costs by sludge processing and disposal method indicated at the 99 per cent confidence level that the per capita sludge disposal costs associated with sludge processing by flotation thickeners and vacuum filters and disposal in landfills were significantly higher than those associated with liquid landspreading, disposal in landfills after dewatering on sand drying beds, and disposal by landspreading after dewatering on sand drying beds. This is probably due to the use of flotation thickeners and vacuum filters which are expensive to purchase, maintain, and operate. No significant differences in per capita disposal costs between the other three methods of processing and disposal could be determined.

Expensive technology may be required due to lack of space for sand drying beds at treatment plants located in more urban areas where space for sand drying beds is not readily available. Large volumes of waste-

water which need to be processed at these treatment plants may also require costly facilities. The implication of this finding is that higher per capita disposal costs may exist for treatment plants when they are forced to use this "higher" technology.

The hypothesis that economic costs involved in landfill disposal are less than the economic costs involved with landspreading disposal could not be supported. The implication of these findings is that choice based on costs of landfill disposal or landspreading disposal must be made on an individual basis, not on the notion that one method is generally less expensive than another.

Linear regressions using per capita costs as the dependent variable and population served by the wastewater treatment plant as the independent variable were performed on the two sample populations of per capita costs of sludge disposal indicated by the analysis of variance. In neither case could it be said with 95 per cent confidence that a linear relationship existed between per capita disposal costs and populations served. The low r^2 value for the regression performed on the 16 observations of per capita costs associated with liquid and sand drying bed dewatered sludge disposal suggests that population served was not very useful in explaining the variation in these costs. Population served in the case of per capita sludge disposal costs associated with treatment plants using flotation thickeners and vacuum filters was much more useful in explaining this variation. The major implication of this finding is that economies of scale within the populations observed were not achieved by treatment plants serving larger populations. The small sample sizes,

particularly in the case of treatment plants using flotation thickeners and vacuum filters, makes it difficult, however, to put much faith in these implications. Larger sample sizes would have been desirable.

Cost elasticities of transportation based on added distances of five and twenty miles to disposal sites were calculated for the nineteen observations of total disposal costs. Total costs of dewatered sludge disposal were not found to be very responsive to changes in distances to disposal sites. Elasticities increased in size as distances to disposal sites increased in these cases, but total disposal costs remained quite unresponsive even to added distances to disposal sites of twenty miles. Disposal by liquid landspreading had the largest cost elasticities of transportation of the four observed processing and disposal methods. This indicated that distances to disposal sites in the case of liquid disposal had a large effect on total disposal costs. It would seem, except in the case of liquid disposal, that the proper choice of disposal method or disposal site should be based on criteria other than distances to disposal sites associated with different methods.

The benefits of both landfill and landspreading methods of sludge disposal were examined. The economic benefit of landspreading sludge disposal, based on the value of its nutrients, was $34.60 per ton. Until economic benefits of sludge in other uses can be quantified, a useful comparison of benefits can not be made. Maximum potential benefits based on the calculated value of sludge and estimates of sludge produced were compared to the nineteen observations of total disposal costs to

indicate the magnitude of the potential value of sludge produced in Vermont and give an indication of the potential for cost recovery through landspreading disposal. The maximum potential economic benefits of sludge ranged from 13 per cent to 352 per cent of the total costs of disposal. The implication is that the potential for cost recovery by society as a whole is very great. Whether or not individual treatment plants could recover part or all of their disposal costs would depend on their ability to market sludge. Price increases of commercial fertilizers similar to those experienced in the past would greatly increase the value of sludge as a fertilizer source. The implication here is that as prices of commercial fertilizers rise the choice of landspreading sludge with its potential for cost recovery will become more and more attractive.

Information gathered during treatment plant operator interviews indicated areas where disposal decisions and disposal costs might be influenced. Weather was seen to often force operators to change schedules and make adjustments in disposal processes. Treatment plant design in several cases, especially where sand drying beds were concerned, appeared to be inadequate. Lack of liquid sludge outlets was seen to limit options available for some treatment plants. The personnel initiative and experience of operators had a great influence on disposal methods and often resulted in reduced disposal costs for individual towns. A lack of cost records and cost accounts of disposal processes was generally found during interviews with treatment plant operators.

Users of sludge were found to have varied motivations. They ranged from doing the town a favor by allowing sludge to be spread on their

land to seeking an alternative to rising fertilizer prices. The application methods and schedules they used varied widely as did the soils on which they applied sludge. Crops on which sludge was used ranged from forage crops to vegetables grown for human consumption, implying that closer monitoring of sludge landspreading practices might be necessary. The time involved in landspreading sludge for those users who spread their own sludge was observed to be the primary concern. The timing of sludge application was also important. Some farmers were already investing considerable amounts of capital and time to obtain sludge. Interviews with potential users showed a modest interest in sludge as a source of fertilizer, but generally, a lack of knowledge concerning sludge existed.

Based on the findings of this study, the potential for cost recovery through the sale of sludge was felt to be large. From the user interviews and the interviews with treatment plant operators it can be concluded that some farmers are willing to pay and have paid, in one way or another, for the benefits they received from sludge. Increased awareness of the value of sludge as a fertilizer and soil conditioner, along with systems by which users could more easily and economically obtain sludge, would greatly reduce many of the problems that individual treatment plants experience in sludge disposal and help reduce costs of disposal.

Regional effort by groups of treatment plants was seen to be one approach that could help reduce many problems of sludge disposal for individual treatment plants. At the same time, the use of sludge for agricultural purposes could be encouraged. The problems of regional

efforts in Vermont were reviewed. A regionalized approch using centralized lagoons as intermediary sludge holding sites between treatment plants and farms was suggested. This approach was seen to have distinct advantages. The problems of limited sludge holding capacities and small quantities of available sludge at individual treatment plants would be eliminated, as would all problems connected with sand drying beds. It was felt that farmers could be better guaranteed when and how much sludge they could expect to get, as well as more precise information concerning the nutrient content of the sludge they were receiving. The reduced processing and transportation costs through the sharing of facilities, as well as the increased potential for cost recovery through the sale of sludge, were seen to be other advantages of this system. In addition, improved environmental conditions through safer and more closely monitored landspreading practices were also perceived to be a possible result of this type of system.

SUGGESTIONS FOR FURTHER RESEARCH

This study was the first attempt to analyze costs and benefits of alternate sewage sludge disposal methods in Vermont. As such, the study was very broad in its approach. Many aspects of sludge disposal methods were surveyed and explored. Limited resources did not allow an in-depth analysis of all aspects of sludge disposal. In many cases a wider data base would have been useful in helping to provide more complete information on all sludge processing and disposal methods used in Vermont. Suggested below are a few of the more important areas that could provide useful information if explored.

Concentration in this study was on total resources used for processing and disposal of sludge, no matter who was paying for them. A closer examination of costs experienced by individual treatment plants or individual farmers would be useful to both treatment plants and farmers. Similarly, benefits of landspreading disposal were viewed from the standpoint of total potential benefits to be received, not from actual benefits received by individual users. An examination and determination of the actual benefits received by individual users of sludge would be useful in determining the expected value from increased landspreading activities.

Increased landspreading disposal would change many disposal costs. An investigation of the changes in these costs would be useful to towns considering alternate methods of disposal. Flotation thickeners, polymers, chemical additives, or, perhaps, increased sludge digestion times

may be used to reduce the volumes of sludge. It would be useful to compare the costs of reducing sludge volumes to the costs of liquid sludge transportation.

Many operators experienced similar problems associated with the weather and sand drying beds in Vermont. An in-depth analysis of how operators dealt with the problems of weather and inadequate sludge processing facilities would be helpful to other operators experiencing similar problems.

Cost records were found to be lacking in most treatment facilities. Further research in this area with an eye toward the development of a simple cost accounting program for wastewater treatment plant operators would be useful and have the potential for improving operational and economic efficiency.

The whole question of which methods of sludge disposal in Vermont are least harmful to the environment needs to be examined more closely. Both landfill and landspreading activities were performed on sites not approved by the state. Pollution resulting from both landfill and landspreading methods of disposal has the potential for being quite harmful. A determination of which treatment plants are using unapproved disposal sites and what could be done about it might lessen this danger. The extent of sludge use on crops grown directly for human consumption needs to be determined and the implications explored.

The area of sludge sales potential and cooperative ventures between farmers and wastewater treatment plants needs to be further investigated. A larger and more precise survey of the users of sludge would be helpful

for purposes of determining the most successful, least expensive methods of landspreading disposal. A closer determination of the costs of sludge, in time and money, would indicate the potential for cost recovery through the sale of sludge. Different types of cooperative efforts between farmers and wastewater treatment plants need to be formulated and their costs estimated for comparative purposes.

Finally, the area of regional efforts among the wastewater treatment plants needs to be examined more closely. New ideas in this area are needed. The centralized sludge lagoon and other approaches to cost sharing among treatment plants need to be examined from a cost-effective and environmental standpoint. Different sludge marketing approaches should also be explored. These investigations should be done with an eye toward reducing the problems and costs associated with sludge disposal and with hopes of fuller and more efficient utilization of the often wasted resource known as sludge.

APPENDIX I

SURVEY OF SLUDGE PROCESSING & DISPOSAL AT MUNICIPAL SEWAGE TREATMENT FACILITIES IN VERMONT

A. General Plant Data

1. Date survey taken:
2. Name of plant:
3. Location of plant:
4. Description of vehicular access to plant site:
5. Plant operator's name and telephone number:

B. Sewage Data

1. Design capacity of plant:
2. Actual use flow (average):
3. Are upgrades planned, when, and what type (nutrient removal or effluent polishing):
4. Size of the population served by the plant:
5. Are there seasonal variations in flow or the population served (maximum daily flows):
6. Characterization of influent (per cents):
   - Residential
   - Industrial
   - Street runoff
   - Infiltration
   - Septage
7. Influent S.S.
   BOD.
8. Effluent S.S.
   BOD.

2

C. Present In-Plant Processing Practices and Costs

1. How is treatment plant financed:

2. Is the plant operating within the budget:

3. Who makes processing and disposal decisions:

4. Sludge processing facilities used:

5. Anaerobic sludge digestion yes no

Number of tanks:

Volume of tanks:

Tank dimensions:

Digester temperature:

Digester pH:

Gas production (FT^3/D):

Facilities to store gas yes no

Describe:

Is gas utilized yes no

Describe:

Gallons of sludge input/day and the pumping schedule:

Supernatant withdrawal schedule:

Sludge transfer schedule:

Sludge withdrawal schedule:

Describe operational problems:

Costs of anaerobic digestion

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

6. Aerobic sludge digestion yes no

Number of tanks:

Volume of tanks:

Tank dimensions:

Digester temperature:

Digester pH:

Gallons of sludge input/day and the pumping schedule:

Supernatent withdrawal schedule:

Sludge withdrawal schedule:

4

Solids concentration input:

Solids concentration output:

Describe operational problems:

Aerobic digester costs

Initial costs:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

7. Holding tanks yes no

Number of tanks:

Volume of tanks:

Tank dimensions:

Aerated yes no

Sludge addition and withdrawal schedule:

Describe operational problems:

Holding tank costs

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

8. Imhoff septic tanks yes no

Number of tanks:

Volume of tanks:

5

Tank dimensions:

Sludge storage:

Sludge withdrawal schedule:

Describe operational problems:

Imhoff septic tank costs

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

9. Vacuum filters yes no

Number of filters:

Cloth area/filter:

Diameter of filter:

Vacuum pressure:

Chemicals used:

Operational schedule (hours/day and days/week):

Number of operators who operate filter:

Describe operational problems:

Vacuum filter costs

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

10. Centrifuge yes no

Number of centrifuges:

Rotational speed:

Bowl diameter:

Through flow rate:

Chemicals used:

Operational schedule (hours/day and days/week):

Describe operational problems:

Centrifuge costs

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, materials, power usage):

11. Chemicals used yes no

Manual or machine fed:

Number of feeders:

7

Type of feeding (solution, slurry, dry):

Chemicals fed:

Feed rate:

Dissolving tank volume:

Hours of clean-up/use:

Feeder costs

Initial cost:

Expected life:

Operations/maintenance costs (man-hours, chemicals, power usage):

12. Sludge drying beds yes no

Number of beds:

Total bed area:

Depth of sludge application:

Are beds covered yes no

Are covers effective yes no

Operational schedule:

Operational problems:

Drying bed costs

Initial cost:

Expected life:

8

Operations/maintenance costs (man-hours, materials, machinery, power usage):

13. Other processing facilities and costs:

D. Sludge Data

1. Process: in %T.S.
Volume
%Volatile
out %T.S.
Volume
%Volatile

2. Process: in %T.S.
Volume
%Volatile
out %T.S.
Volume
%Volatile

3. Process: in %T.S.
Volume
%Volatile
out %T.S.
Volume
%Volatile

9

4. Process: in %T.S.
Volume
%Volatile
out %T.S.
Volume
%Volatile

5. What sludge records are kept:

6. Nutrient analysis
Nitrogen
Phosphorus
Potassium

7. Other analysis (pH, heavy metals, pathogen counts):

8. % solids destruction in digester:

9. How long are solids kept in the digester tanks:

At what temperature:

E. Calculations

1. lbs. S.S. removed/day:

2. lbs. BOD. removed/day:

3. conversion factor (lbs. S.S. removed/lbs. BOD. removed):

4. lbs. of S.S. produced/day as a result of BOD. removal:

5. lbs. dry solids produced/day (calculated):

16

F. Present Disposal Practices and Costs

1. Persons who remove sludge from premises:

2. Equipment used and owners of the equipment:

3. Type and location of ultimate disposal sites (landfill farms, distance from plant):

4. If landfill, is it state approved yes no

5. Is final sludge stored before disposal yes no

6. Describe disposal operation:

7. Describe operational problems, including seasonal problems:

8. Proximity of plant to town parks, playgrounds, schools, ball fields, etc.:

9. Proximity to farmlands:

10. Is there private removal yes no

Describe:

11

11. Disposal costs

Initial equiptment costs:

Expected life:

Scrap value:

Operations/maintenance costs (man-hours, mileage, miles/gallon, insurance, registration, materials used):

Disposal site costs:

C. Environmental Considerations

1. Any complaints from odors, flies, noise, groundwater contamination, etc.:

2. Description of disposal site proximity to water sources:

3. How accessable is disposal site to the public:

4. Other environmental considerations:

H. Are there any ways the operator feels the town could save money on either processing or disposal, including more private removal:

APPENDIX II

User 900 Date: 6jul77 Time:12:32:05 File: 8

Set	Items	Description
1	644	RURAL
2	413	TOWN
3	4	SMALL (W) COMMUNITY
4	14	SMALL (W) COMMUNITIES
5	2907	AGRICULTURAL
6	3933	1-5/OR
7	2116	SLUDGE
8	723	TREATMENT (W) PLANT
9	1197	TREATMENT (W) PLANTS
10	8576	WASTE
11	3859	WASTES
12	12017	7-11/OR
13	4224	DISPOSAL
14	6695	REMOVAL
15	60986	USE
16	176	SALE
17	604	SALES
18	153	SELLING
19	1978	ELIMINATION
20	72333	13-19/OR
21	265	6AND12AND20
22	25313	COST?
23	618	BUDGET?
24	1481	PRICE
25	176	SALE
26	6149	TRANSPORTATION
27	77165	METHOD
28	105770	22-27/OR
29	38	21AND 28
30	78547	12OR20
31	1234	6AND30
32	252	28AND31
33	214	32NOT29

Print 29/5/1-38

Search Time: 0.244 Prints: 38 Descs.: 27

APPENDIX III

QUESTIONS FOR USERS - WATER RESOURCES RESEARCH (C-2509)

1. Name : _____

2. Date of Survey: _____

3. Location of and access of farm to treatment facilities:

4. How did you find out about sludge and come to use it?

5. Where and how did/ do you get your sludge?

6. On what crops and soil types do you use sludge?

7. What is your sludge application schedule? What type of spreading device is used? Can you estimate the quantity of sludge used per unit of time?

USERS' QUESTIONS - PAGE 2

8. Have you done or do you know of an analysis performed on the sludge? Nutrient content? ph? heavy metals? Pathogens?

9. What knowledge do you have of regulations governing the use of sludge?

10. Is the application of sludge to your land state approved?

11. What do you perceive as the benefits of applying sludge to your land?

12. What are the disadvantages to using sludge on your land? Unsatisfactory delivery technique? Unsatisfactory quality? Unsatisfactory results of use?

13. Do you use the same amount of commercial fertilizer on the areas where sludge is spread as on other areas?

USERS' QUESTIONS - PAGE 3

14. Have you or could you calculate the money you save or earn by using sludge? What does it cost you to spread sludge? Time? Equipment? Transportation?

15. Would youpay for the sludge you use (contribute to the cost of delivery, etc.)?

APPENDIX IV

QUESTIONS FOR NON-USERS - WATER RESOURCES RESEARCH ES-25097

1. Name:_____

2. Date of Survey:_____

3. Location of/ and access of farm to treatment facilities:

4. What type of crops do you produce? What are the soil types the crops are grown on?

5. What do you know about sewage sludges use as a fertilizer and soil conditioner?

6. Would you prefer to continue to use or else where could you use it? Nutrient or soil conditioning value? Disadvantages?

7. What do you know about regulations governing the application of sludge to cropland?

8. To what extent would you be willing to go to get sludge applied to your land? (Consider the physical amount in comparison to fertilizer and manure?)

9. Would you pay money for it? (Contribute to transportation cost? Under what conditions would you be willing to use it?)

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